621.1
H24f
V.2

FINDING AND STOPPING WASTE IN MODERN BOILER ROOMS

VOLUME II

HARRISON SAFETY BOILER WORKS
PHILADELPHIA, PA.

THE UNIVERSITY
OF ILLINOIS
LIBRARY

621.1
H24f
v.2

[redacted]

Date Due

[illegible]

24 Mr 22

1248

Digitized by the Internet Archive
in 2016

https://archive.org/details/findingstoppingw02harr

"Knowledge rests upon measurements"

FINDING AND STOPPING WASTE IN MODERN BOILER ROOMS

VOLUME II

A Reference Manual to Aid the
Owner, Manager and Boiler
Room Operator in Securing and
Maintaining Plant Economy

Price, $1.00

HARRISON SAFETY BOILER WORKS
PHILADELPHIA, PENNSYLVANIA

**Builders of the Celebrated Cochrane Line of Open Feed Water Heaters,
Heaters and Receivers, Meters and Metering Heaters, Hot
Process Water Softeners, Steam and Oil
Separators and Multiport Valves**

PUBLICATION No. 821

COPYRIGHT 1918

Contents

Section I—Fuels:

Page

Classification of coals 5
Coals of the United States 10
Size of coal 14
Coal sampling 15
Proximate analysis 23
Ultimate analysis 28
Heating value of coal 31
Ash and clinker 36
Value of coal for steam purposes 41
Purchase of coal under specifications 45
Washing of coal 57
Storage and weathering of coal 57
Coal measurement 59
Oil fuels 60
Gaseous fuels 64

Section II—Combustion:

Chemistry of combustion 66
Air theoretically required 67
Grates and grate surface 72
Hand firing methods 73
Thickness of fire 81
Mechanical stokers and their operation 84
Furnace temperature 100
Furnace gases 106
Clinker 109
Draft 110
Flue proportions 115
Stack proportions 119
Draft required by stokers 129
Mechanical draft 132
Draft gauges 135
Dampers 137
Flue gas temperature 139
Analysis of gases of combustion 144
CO_2 Recorders 151
What CO_2 indicates 156
What CO indicates 158
Air requirements and supply 161

621.1
H24f
v.2

Page
Preventing excess air 166
Smoke and smoke prevention 167
Burning oil fuel 180
Burning gaseous fuels 182
Burning powdered coal 182

Section III—Heat Absorption:

Heat transmission 187
Conduction 187
Convection 190
Radiation 192
Heat transfer from fluid in a channel 197
Economizers, air heaters and superheaters 200
Improving absorption 206
Heating surface and boiler capacity 209
Boiler settings 211
Refractories and fire brick 213
Soot 216
Scale 217
Softening feed water 222
Feed water heating 224

Section IV—Boiler Efficiency and Boiler Testing:

Heat balance 227
Heat absorbed by boiler 227
Loss due to moisture in coal 228
Loss due to hydrogen 231
Loss in chimney gases 232
Loss due to CO 234
Loss due to combustible in ash 235
Loss due to moisture in air 237
Loss unaccounted for 238
Efficiencies 238
Efficiencies with different coals 240
Boiler capacity and efficiency 245
Boiler trials 246
Conversion factors 249

Section V—Boiler Plant Proportioning and Management:

Boiler plant proportioning 251
Feed heating and heat balancing 254
Boiler plant management 258
Cochrane Meters 263

Mech. enc. 29 Apr. 18 McClurg. =V.2.

394342

PREFACE

THE subject matter of this hand-book, originally intended as an appendix to our Catalog of Cochrane V-Notch Meters, has grown to require a separate volume. The information has been selected with a view to its service to owners, managers, engineers and firemen in increasing and maintaining boiler plant economy. We have preferred such statements, tables, charts, etc., as were supported by experiments and tests, and, wherever possible, have given references to the original authority.

In view, however, of the great range and diversity of the subjects necessarily comprised in a treatment of boiler-plant economy, it has obviously been impracticable to test every statement by experience, but considerable pains have been taken to check each authority against others. Mr. Henry Kreisinger, who conducted for the United States Bureau of Mines many of the steam boiler investigations mentioned in the following pages, has also kindly read and corrected the proof sheets.

Using such information as is here presented, the owner or user of a Cochrane Meter or Metering Heater is enabled to increase the economy of his plant by trying one by one the effects of changes in fuels and of improvements in methods and equipment. Having determined from the indications of the Meter which fuels, methods and arrangements are best, they can be standardized, and the Meter will thereafter show whether or not these maximum possibilities are being realized in daily practice.

HARRISON SAFETY BOILER WORKS.

August 3, 1917.

Section I—Fuels

CLASSIFICATION OF COALS

Wood fibre or cellulose is the lowest group in a carboniferous series, including peat, lignite, bituminous coal, semi-bituminous coal, semi-anthracite, anthracite and graphite. The lower groups are low in carbon and high in oxygen. Each succeeding group is distinguished by an increase in carbon and a decrease in oxygen. The hydrogen remains practically the same for all groups below the semi-bituminous, but decreases rapidly in the higher groups.

It is difficult to define each group exactly. One method is according to the percentage of volatile matter, as in the table from *Steam* given below:

Name	% Fixed Carbon	% Volatile	BTU per lb. Combustible
Anthracite	97 to 92.5	3 to 7.5	14600 to 14800
Semi-anthracite	92.5 to 87.5	7.5 to 12.5	14700 to 15500
Semi-bituminous	87.5 to 75	12.5 to 25	15500 to 16000
Bituminous Eastern	75 to 60	25 to 40	14800 to 15300
Bituminous Western	65 to 50	35 to 50	13500 to 14800
Lignite	Under 50	Over 50	11000 to 13500

M. R. Campbell has suggested a classification based upon the carbon-hydrogen ratio. Carbon and hydrogen are both valuable fuel elements, hence both should be taken into account. *Cosgrove* divides coals into twelve groups, as given in the table below. The bituminous coals are divided into four groups, where ordinarily there is no distinction made, the low-grade fuels of the Mississippi Valley being separated in his classification from the high-class coals of the Appalachian region.

Class	Group	Ratio=C/H
Anthracite	A	Over 30
Anthracite	B	
Anthracite	C	30 —26
Semi-anthracite	D	26 —23
Semi-bituminous	E	23 —20
Bituminous	F	20 —17
Bituminous	G	17 —14.4
Bituminous	H	14.4—12.5
Bituminous	I	12.5—11.2
Lignite	J	11.2— 9.3
Peat	K	9.3
Wood	L	7.2

The following characterizations of the different coals have been suggested by the *U. S. Geological Survey*, *Steam* and *Cosgrove*:

Graphite is not available for fuel, because of the high temperature required for its ignition.

Anthracite, commonly known as **hard coal**, is practically all fixed carbon. It has a deep black color, a shiny, semi-metallic luster, few joints and clefts, and is compact and sometimes iridescent. The specific gravity ranges from 1.3 to 1.8. Anthracite neither softens nor swells when burning. It kindles slowly and with difficulty and burns with a short, yellowish flame, which changes to a faint blue, and is transparent in appearance, owing to the absence of particles of solid carbon.

Semi-anthracite is not so hard or dense, and does not have the luster of true anthracite. It can be distinguished by the fact that when newly fractured it will soot the hand. The specific gravity is about 1.4. Semi-anthracite contains more gaseous matter, and for that reason kindles more readily and burns more rapidly than the true anthracite. It makes a very intense, free-burning fire.

Semi-bituminous coal is still softer than the semi-anthracite, and lacks most of the bright metallic luster, although it is brighter in appearance than bituminous coal. It contains more volatile hydrocarbon, kindles more easily and burns more rapidly than the anthracite, but resembles anthracite more than it does bituminous coal. It is ordinarily free-burning, without smoke, and has a high calorific value. It is of the highest class for steam generating purposes.

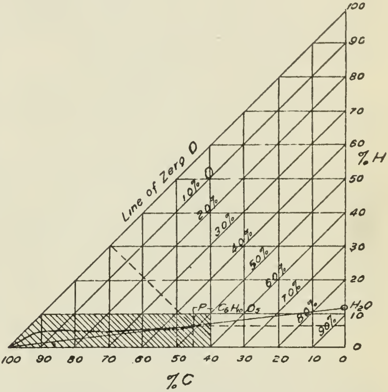
Bituminous coals are commonly called **soft coals.** They consist of fixed carbon and bitumen. This is a mixture of hydrocarbons, which, when heated, breaks down into gases, oils and tars. Bituminous coals have more volatile matter than the preceding classes. The range in specific gravity is from 1.25 to 1.4, and the color from dark brown to pitch black. In hardness they range from lignite to semi-bituminous. The harder varieties have the best heating values. Generally bituminous coals are brittle, with a vitreous, resinous or greasy luster. The distinction between semi-bituminous and bituminous coals is important economically, for the semi-bituminous have about 6% higher heating value per pound of combustible, and burn with much less smoke. Bituminous coals absorb moisture from the atmosphere. The surface moisture will dry out naturally, but the moisture absorbed internally is driven out only at a temperature of 250° F. A distinguishing characteristic is a yellow flame and smoke when burning. There are two types of bituminous coals, designated generally as caking coals, and non-caking or free-burning coals. Caking coals are very rich in hydrocarbons, and valuable therefore in gas manufacture. They fuse and swell when heated. Non-caking coals do not fuse, but hold their shape, burn much more freely, and are preferable for steam purposes.

Sub-bituminous coal is frequently called black lignite, and is not readily distinguishable from either lignite or bituminous coals. Its chief characteristic is its tendency to absorb moisture if exposed to the weather, and to slake like lime. It has a fairly bright luster.

Lignite is sometimes called brown coal, and is vegetable matter in the early stages of coal formation. The specific gravity ranges from 1.2 to 1.23. When first mined, it may contain up to 50% of moisture. The color is light brown, showing a distinct woody structure in the poorer varieties, ranging to black with a pitchy luster resembling hard coal, in the best varieties. It is non-caking, and burns with a slightly smoky flame, with moderate heat. It is easily broken, and will not stand handling in transportation. The ash content of lignite ranges from 1 to 50%. It is distinctly a low-grade fuel, but cheap.

Peat is organic matter in the first stages of conversion to coal. It is found in bogs. The moisture averages 75 to 80%. It is unsuitable for fuel until dried, and then may contain as high as 30% moisture. Large deposits are found in this country, but as yet are little used.

The classification and nomenclature of coals on a scientific basis are desirable, but do not always agree with classifications based on the behavior of coals in practical use. *O. C. Rolston* presents a graphic study of coal, based on trilinear coordinates, as shown in the adjoining chart. The coal analysis is computed to a moisture-free, ash-free, nitrogen-free and sulphur-free basis, so that the percentages of carbon, hydrogen, and oxygen added equal 100%. These three constituents are considered to be the important ones in the coal. The points representing actual coals fall in the shaded portion of the small chart, which is reproduced in the large charts on page 9.



PRINCIPLE OF TRILINEAR COORDINATES ON ISOSCELES RIGHT TRIANGLE, USED IN PLOTTING COAL ANALYSES. THE SUM OF THE DISTANCES FROM ANY POINT TO THE SIDES IS A CONSTANT (100%).

The first chart represents a group of analyses collected and plotted by the *Bureau of Mines*. The coals formerly classified as anthracite, semi-anthracite, semi-bituminous, etc., fall into certain definite groups, which overlap to only a small extent. The coal analyses plotted occupy a narrow band across the diagram. The width of this band is considerably more than that due to the total error of analysis, so that it cannot be assumed that the band would narrow to a line if all errors were eliminated. This shows why former investigators have failed to reach conclusions that apply to all coals from a consideration of the ratios of carbon to oxygen, or hydrogen to oxygen alone, as coals on the two sides of the band differ distinctly, but are very close in composition. The zero "available hydrogen" line shows the percentage of hydrogen which can be considered to be bound up with the percentage of oxygen in the coal. The difference between this and the percentage of hydrogen in the coal can be considered to be the available hydrogen.

There is a fairly definite relation between the calorific value of a coal and its ultimate analysis, and a similar relation between the volatile matter of a coal and its ultimate analysis. Lines drawn through dots representing coals of equal calorific value, which may be called "isocalorific" lines, are almost straight and nearly parallel, running diagonally across the band, as shown on page 9. A correction has been made for the heating value of sulphur. Similar lines, called "isovolatile" lines, can be drawn connecting coals of equal volatile content, but the lines run transversely to the isocalorific lines.

"The fact that fairly good relations are shown between the ultimate analysis and such factors as volatile content and calorific value, and possibly moisture content, can be utilized in predicting the other properties of a coal when only a few are known, as a complete analysis will not be necessary to identify a particular fuel."

The diagram containing both the isocalorific and the isovolatile lines can be used to obtain an idea of the ultimate analysis when the volatile content and the heating value are known.

The separate fields overlap but slightly. This is remarkable when it is remembered that the classification of most of the samples was made by field men more from the physical characteristics than from the analysis, and when the analyses were considered it was the proximate rather than the ultimate that influenced the classification. The sub-bituminous and lignite fields seem to overlap more than the others. This is due to the fact that in the early analyses some of the fuels which belong in the sub-bituminous fields were designated black lignite. The diagram seems to offer a satisfactory method of classifying coals according to their ultimate analyses.

The chart below shows a field in which lie coking coals. Only such coals as were known to be used for coke were plotted by the *Bureau of Mines*. Many other coals whose analyses have been published might have the property of coking. Most of the coking coals lie near the sharp bend in the average coal curve, that is, they are low in oxygen and high in hydrogen, which tends to uphold the theory that resinous substances impart a coking property to coal. The diagram agrees with *Parr's* criterion that coals known to be coking are the highest in available hydrogen and *White's* statement that coking coals show the highest hydrogen-oxygen ratio.

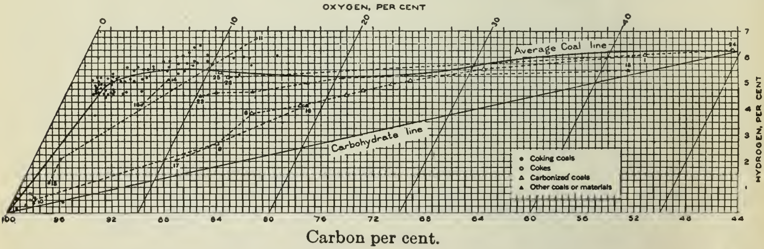


DIAGRAM SHOWING GROUPING OF COALS, ETC., ACCORDING TO CARBON, HYDROGEN AND OXYGEN CONTENTS.

The table on the following pages contains a collection of analyses of typical coals from all parts of the country.

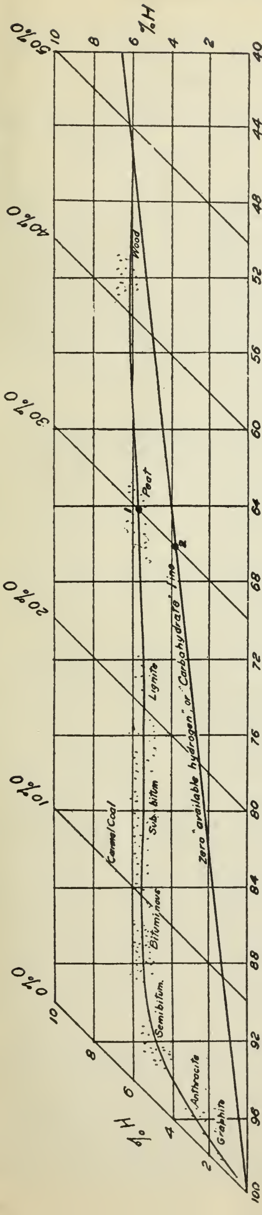


DIAGRAM SHOWING GROUPING OF COALS ACCORDING TO CARBON, HYDROGEN AND OXYGEN CONTENTS. (*U. S. Bureau of Mines*, as redrawn by *Sibley Journal.*)

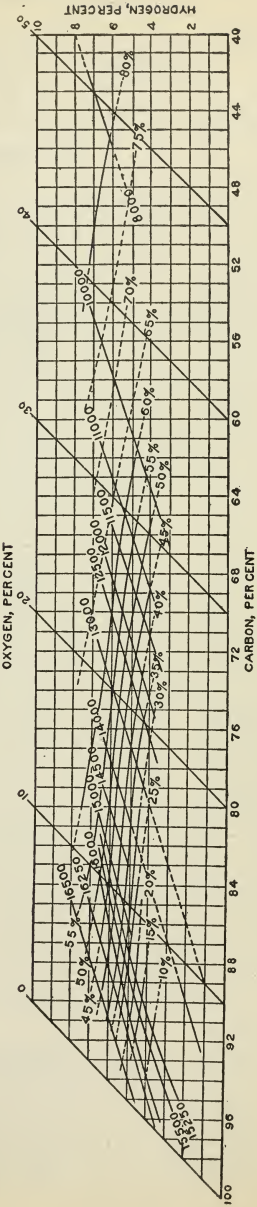


DIAGRAM SHOWING RELATIONS OF ISOCALORIFIC AND ISOVOLATILE LINES

COALS OF THE UNITED STATES

(Taken from *Bureau of Mines* Bulletins.)

(*) indicates samples from car deliveries; all others are mine samples.

County Bed or Local Name	Proximate Analysis "As Received"				Ultimate Analysis "As Received"					Heating Value B.T.U. per Lb. "As Received"
	Moisture	Volatile Matter	Fixed Carbon	Ash	Sulphur	Hydrogen	Carbon	Nitrogen	Oxygen	
Alabama										
Bibb, Belle Ellen	3.16	31.05	59.56	6.23	1.20	5.33	78.28	1.37	7.59	14,141
Jefferson, Dolomite	3.16	25.40	67.75	3.69	.56	5.05	82.28	1.36	7.06	14,616
Jefferson, Littleton	2.53	26.94	59.48	11.05	.79	4.80	74.44	1.59	7.33	13,286
St. Clair, Davis (Tillman Sta.)	3.39	30.69	57.08	8.84	2.34	5.18	73.81	1.53	8.30	13,363
Shelby Straven	3.83	32.03	58.66	5.48	.97	5.29	77.26	1.25	9.75	13,799
Tuscaloosa, Abernant	2.62	24.18	64.11	9.09	.64	4.72	77.52	1.48	6.55	13,729
Alaska										
Alaska Peninsula, Chignik Bay, Thompson Valley	10.77	30.37	43.99	14.87	.70	4.98	55.27	.61	23.57	9,641
Bering River, Hartline	4.75	13.72	63.31	18.22	.62	3.14	65.93	1.32	10.77	10,820
Cook Inlet, Port Graham	19.96	38.73	32.46	8.85	.52	5.81	49.53	.92	34.37	8,793
Matanuska, Matanuska River	1.72	24.36	58.97	14.95	.46	4.46	70.78	1.42	7.93	12,585
Seward Peninsula, Chicago Creek	37.82	26.14	32.16	3.88	.65	6.12	41.79	.67	45.89	
Arizona										
Navajo, Oraibi	9.88	32.64	46.86	10.62	1.12	5.42	62.00	1.13	19.71	10,800
Arkansas										
Logan, Paris	2.77	14.69	73.47	9.07	2.79	4.02	78.71	1.46	3.95	13,774
Pope, Russellville	2.07	9.81	78.82	9.30	1.74	3.62	80.28	1.47	3.59	13,702
Sebastian, Greenwood	3.21	14.84	72.66	9.29	3.12	3.75	78.37	1.52	3.95	13,588
California										
Monterey, Stone Canyon	6.95	46.69	40.13	6.23	4.17	6.28	66.01	1.17	16.14	12,447
Colorado										
Boulder, Lafayette	19.15	30.82	44.27	5.76	.25	5.93	56.38	1.08	30.60	9,616
El Paso, Pikeview	26.20	29.67	37.67	6.46	.30	6.13	49.36	.66	37.09	8,352
Garfield, Newcastle	4.45	42.05	49.56	3.94	.44	5.43	72.57	1.72	15.90	13,129
Montezuma, Cortez	3.89	37.01	46.58	12.52	7.04	4.96	66.19	1.16	8.13	12,341
Weld, Platteville	28.90	28.83	37.25	5.02	.46	6.64	48.36	.93	38.59	8,465
Georgia										
Chattooga, Menlo	3.80	15.88	65.83	14.49	1.27	4.32	70.59	1.09	8.24	12,791
Idaho										
Fremont, Haden	11.45	37.24	47.01	4.30	.54	5.94	68.09	1.40	19.73	12,094
Illinois										
Clinton, *Germantown	11.35	34.62	40.63	13.40	4.76	5.41	57.36	1.05	18.02	10,733
Franklin, Zeigler	11.82	27.66	55.10	5.42	.46	5.44	67.87	1.34	19.47	11,961
La Salle, *La Salle	12.39	36.89	41.80	8.92	3.92	5.85	61.29	1.00	19.02	11,399
Macoupin, *Staunton	13.54	35.69	40.03	10.74	4.03	5.71	58.69	.95	19.88	10,807
Madison, Collinsville	12.70	36.36	41.47	9.47	3.67	5.81	60.91	.99	19.15	10,989
Marion, *Centralia	9.95	34.76	42.06	13.23	3.87	5.25	59.64	1.04	16.97	10,960
Montgomery, Panama	13.31	33.62	41.34	11.73	3.75	5.19	59.07	.95	19.31	10,548
St. Clair, *Shiloh	11.69	35.70	39.42	13.19	4.38	5.46	57.15	.94	18.88	10,699
Saline, Harrisburg	6.01	32.37	54.32	7.30	1.66	5.27	71.63	1.34	12.80	12,793
Sangamon, *Auburn	16.00	32.41	37.82	13.77	4.05	5.55	53.89	.91	21.83	9,940
Williamson, Carterville	9.18	27.30	55.40	8.12	.90	5.10	68.45	1.14	16.29	12,015
Williamson, Herrin	8.80	29.85	53.83	7.52	1.13	5.08	68.70	1.33	16.24	12,222
Indiana										
Clay, *Brazil	16.91	26.85	38.87	17.37	1.89	5.48	52.97	1.01	21.28	9,524
Greene, *Linton	13.58	32.07	46.20	8.15	.91	5.65	63.53	1.42	20.34	11,419
Knox, *Bicknell	12.08	32.48	44.42	11.02	3.65	5.34	60.45	.89	18.65	11,011
Parke, *Rosedale	10.72	39.29	41.42	8.57	3.83	5.86	63.48	1.16	17.10	11,767
Pike, *Littles	11.12	36.98	42.55	9.35	3.78	5.63	63.01	1.13	17.10	11,549
Sullivan, Dugger	13.48	32.51	48.38	5.63	1.09	5.94	66.01	1.49	19.84	11,788
Vigo, *Macksville	12.82	34.80	42.08	10.30	3.27	5.66	61.16	1.03	18.58	11,119
Warrick, Elberfeld	9.69	38.59	41.04	10.68	4.79	5.39	62.36	1.28	15.50	11,412

County Bed or Local Name	Proximate Analysis "As Received"				Ultimate Analysis "As Received"					Heating Value B.T.U. per Lb. "As Received"
	Moisture	Volatile Matter	Fixed Carbon	Ash	Sulphur	Hydrogen	Carbon	Nitrogen	Oxygen	
Iowa										
Appanoose, *Centerville	14.08	35.59	39.37	10.96	4.26	5.57	58.49	.90	19.82	10,723
Lucas, *Chariton	15.39	30.49	41.49	12.63	3.19	5.74	55.81	1.14	21.49	10,242
Polk, *Altoona	13.88	36.94	35.17	14.01	6.15	5.52	54.68	.84	18.80	10,244
Wapello, *Laddsdale	8.24	30.74	45.02	16.00	5.03	4.81	59.82	.94	13.40	11,027
Kansas										
Cherokee, *Scammon	2.50	33.80	51.25	12.45	5.68	4.91	69.07	1.20	6.69	12,900
Crawford, Fuller	4.85	33.53	52.52	9.10	4.95	5.08	71.20	1.24	8.43	12,942
Leavenworth, Lansing	11.10	35.51	40.69	12.70	3.99	5.30	60.72	1.13	16.16	11,065
Linn, *Jewett	9.04	29.69	45.55	15.72	3.72	5.01	60.99	1.06	13.50	11,142
Kentucky										
Johnson, Flambeau	2.36	48.40	38.75	10.49	1.20	6.47	71.98	1.16	8.70	13,770
Muhlenberg, Central City	8.73	37.76	45.93	7.58	2.65	5.52	67.65	1.42	15.18	12,208
Ohio, McHenry	9.89	35.94	43.36	10.81	3.64	5.37	62.27	1.33	16.58	11,392
Pike, Hellier	3.73	30.01	59.42	6.84	.56	5.07	76.30	1.06	10.17	13,649
Webster, Wheatcroft	6.29	31.97	54.13	7.61	1.35	5.49	69.78	1.37	14.40	12,874
Maryland										
Allegany, Eckhart	2.70	14.50	74.00	8.80	1.00	4.44	79.21	1.69	4.86	13,910
Allegany, Frostburg	3.20	14.50	75.60	6.70	.92	4.51	80.99	1.77	5.11	14,100
Allegany, Lord	2.26	16.05	75.86	5.83	.79	4.68	82.45	1.73	4.52	14,483
Allegany, Midland	3.10	15.50	74.50	6.90	.86	4.57	80.71	1.69	5.32	14,070
Allegany, Washington	3.40	15.00	75.10	6.50	1.04	4.63	80.69	1.55	5.60	14,160
Michigan										
Saginaw, Saginaw	11.91	31.50	49.75	6.84	1.24	5.84	66.56	1.19	18.33	11,781
Missouri										
Adair, Kirksville	15.98	38.15	37.18	8.69	4.12	5.90	59.09	.94	21.26	10,798
Caldwell, Hamilton	10.99	35.00	41.37	12.64	4.81	5.43	60.40	1.16	15.56	11,093
Henry, Windsor	13.51	33.24	41.88	11.37	4.08	5.89	59.16	.85	18.65	10,779
Lafayette, Napoleon	13.44	32.00	40.27	14.29	3.08	5.62	55.83	.98	20.20	10,232
Macon, Bevier	16.25	33.38	40.97	9.40	3.41	5.75	58.25	1.05	22.14	10,625
Ray, Richmond	13.56	34.29	40.66	11.49	3.77	5.65	58.16	1.04	19.89	10,771
Montana										
Carbon, Bear Creek	9.67	35.92	46.39	8.02	1.64	5.52	61.66	1.48	21.68	10,832
Cascade, Geyser	8.76	25.72	50.36	15.16	3.91	4.40	58.93	.79	16.81	10,127
Custer, Miles	29.13	25.33	30.51	15.03	.55	5.60	40.09	.54	38.19	6,662
Fergus, Lewistown	15.35	28.27	48.08	8.30	4.53	5.42	61.15	.71	19.89	10,615
Missoula, Missoula	24.70	29.33	26.11	19.86	.85	5.56	39.04	.74	33.95	6,727
Yellowstone, Musselshell	16.66	27.85	48.07	7.42	1.00	5.61	59.22	.97	25.78	10,226
New Mexico										
Colfax, Raton	2.12	36.06	50.22	11.60	.64	4.94	69.96	1.33	11.53	12,965
Lincoln, White Oaks	2.52	34.63	45.99	16.86	.76	4.97	66.65	1.32	9.44	11,956
M'Kinley, Blackrock	14.69	34.93	41.56	8.82	.79	5.82	60.93	1.12	22.52	10,809
North Dakota										
Morton, Leith	36.18	29.77	25.35	8.70	.68	6.76	39.45	.59	43.82	6,700
M'Lean, *Wilton	35.96	31.92	24.37	7.75	1.15	6.54	41.43	1.21	41.92	7,069
Stark, *Lehigh	35.38	29.59	25.68	9.35	1.55	6.61	40.23	.54	41.72	6,923
Williams, *Williston	36.78	28.16	29.97	5.09	.48	6.93	41.87	.69	44.94	7,204
Ohio										
Belmont, *Bellaire	4.14	39.30	47.18	9.38	3.96	5.19	69.58	1.20	10.69	12,874
Guernsey, *Danford	6.65	33.94	48.86	10.55	3.13	5.30	67.38	1.20	12.44	12,179
Jackson, *Wellston	7.71	38.32	42.02	11.95	4.61	5.41	62.49	1.11	14.43	11,515
Jefferson, Amsterdam	3.50	37.98	51.08	7.44	3.09	5.43	73.39	1.46	9.19	13,286
Noble, Belle Valley	5.15	37.34	49.00	8.51	2.94	5.42	70.51	1.50	11.12	12,733
Perry, *Dixie	7.55	38.00	46.08	8.37	2.84	5.48	67.02	1.29	15.00	12,128
Oklahoma										
Coal, Lehigh	7.07	36.41	45.68	10.84	3.64	5.13	64.38	1.44	14.57	11,468
Haskell, McCurtain	2.70	21.07	69.88	6.35	.77	4.46	81.33	1.67	5.42	14,098
Pittsburg, Carbon	2.09	27.59	50.25	20.07	5.73	4.46	63.66	1.33	4.75	11,695
Pittsburg, McAlester	3.58	32.11	59.04	5.27	.56	5.31	77.11	1.62	10.13	13,615
Oregon										
Coos, Beaver Hill	16.10	31.10	39.63	13.17	.81	5.53	51.07	1.19	28.23	9,031

County Bed or Local Name	Proximate Analysis "As Received"				Ultimate Analysis "As Received"					Heating Value B.T.U. per Lb. "As Received"
	Moisture	Volatile Matter	Fixed Carbon	Ash	Sulphur	Hydrogen	Carbon	Nitrogen	Oxygen	
Pennsylvania										
Allegheny, Bruceton	2.73	36.03	54.98	6.26	1.39	5.26	76.82	1.46	8.81	13,815
Allegheny, Oak Station	3.48	35.15	55.45	5.92	1.18	5.42	75.73	1.45	10.30	13,700
Allegheny, Scott Haven	2.60	32.67	59.41	5.32	.77	5.39	78.16	1.45	8.91	14,085
Bedford, Hopewell	1.58	16.32	69.98	12.12	1.94	4.09	77.01	1.44	3.40	13,408
Cambria, Barnesboro	2.87	21.44	69.23	6.46	1.52	5.00	80.53	1.19	5.30	14,177
Cambria, Beaverdale	3.44	16.18	73.46	6.92	1.83	4.64	80.61	1.20	4.80	14,114
Cambria, Carrolltown Road	.93	23.10	69.29	6.68	1.30	4.81	81.64	1.26	4.31	14,485
Cambria, Fallen Timber	3.34	24.06	62.75	9.85	1.80	4.96	76.78	1.25	5.36	13,618
Cambria, Hastings	2.89	23.67	66.34	7.10	1.37	5.02	79.49	1.30	5.72	14,107
Cambria, Johnstown	1.32	14.63	75.24	8.81	1.57	4.26	81.19	1.39	2.78	14,047
Cambria, Nanty Glo	2.84	19.78	70.89	6.49	1.85	4.87	80.83	1.32	4.64	14,285
Cambria, Portage	3.52	17.32	73.27	5.89	1.06	4.78	82.06	1.23	4.98	14,278
Cambria, St. Benedict	2.94	19.52	70.87	6.67	1.76	5.04	79.78	1.26	5.49	14,143
Cambria, Van Ormer	2.73	24.98	63.64	8.65	.81	4.89	78.24	1.22	6.19	13,860
Cambria, Vintondale	3.63	18.63	71.20	6.54	1.98	4.90	80.59	1.23	4.76	14,119
Cambria, Windber	3.30	12.50	77.90	6.33	1.04	4.46	81.65	1.27	5.25	14,340
Center, Osceola Mills	2.08	21.46	69.87	6.59	1.99	4.92	80.58	1.29	4.63	14,274
Clarion, Blue Ball Station	1.90	22.00	66.30	9.80	1.95	4.66	78.05	1.14	4.40	13,760
Clearfield, Boardman	2.95	21.29	66.92	8.84	1.35	4.74	78.51	1.19	5.37	13,901
Clearfield, Philipsburg	.90	21.59	68.49	9.02	1.99	4.57	79.49	1.31	3.62	14,060
Clearfield, Smoke Run	3.73	20.29	68.41	7.57	1.33	4.86	78.92	1.22	6.10	13,970
Fayette, Connellsville	3.24	27.13	62.52	7.11	.95	5.24	78.00	1.23	7.47	13,919
Indiana, Clymer	2.06	24.46	66.09	7.39	2.19	5.08	79.39	1.19	4.76	14,170
Indiana, Glen Campbell	3.08	27.32	61.16	8.44	1.29	4.99	76.71	1.27	7.30	13,772
Jefferson, Sykesville	2.44	28.44	60.68	8.44	1.32	5.07	76.91	1.31	6.95	13,732
Lackawanna, Dunmore	3.43	6.79	78.25	11.53	.46	2.52	78.85	.77	5.87	12,782
Luzerne, Pittston	2.19	5.67	86.24	5.90	.57	2.70	86.37	.91	3.55	13,828
Schuylkill, Minersville	2.76	2.48	82.07	12.69	.54	2.23	79.22	.68	4.64	12,577
Schuylkill, Tower City	3.33	3.27	84.28	9.12	.60	3.08	81.35	.79	5.06	13,351
Somerset, Jerome	1.44	15.21	73.38	9.97	.90	4.17	79.43	1.34	4.19	13,799
Somerset, MacDonaldton	1.03	16.03	72.57	10.37	2.22	4.29	79.17	1.24	2.71	13,700
Somerset, Windber	2.40	13.50	77.80	6.31	1.26	4.44	82.62	1.31	4.06	14,370
Sullivan, Lopez	3.16	8.59	78.08	10.17	.67	3.47	79.49	1.10	5.10	13,376
Washington, Marianna	1.44	34.61	57.77	6.18	.78	5.23	78.76	1.44	7.61	14,242
Westmoreland, Greensburg	2.14	30.02	58.81	9.03	1.17	5.03	76.33	1.56	6.88	13,662
Rhode Island										
Newport, Portsmouth	22.92	2.78	58.37	15.93	.10	2.84	58.46	.18	22.49	8,528
Providence, Cranston	4.54	3.01	78.69	13.76	.87	.46	82.39	.12	1.75	11,624
South Dakota										
Perkins, Lodgepole	39.16	24.68	27.81	8.35	2.22	6.60	38.02	.53	44.28	6,307
Tennessee										
Anderson, Briceville	1.70	35.02	53.14	10.14	1.06	4.97	75.32	1.80	6.71	13,462
Campbell, Lafollette	2.92	32.04	58.23	6.81	1.14	5.19	74.95	1.62	10.29	13,514
Rhea, Dayton	1.76	27.86	49.57	20.81	.49	4.51	66.24	1.19	6.76	11,666
Texas										
Houston, Crockett	34.70	32.23	21.87	11.20	.79	6.93	39.25	.72	41.11	7,056
Wood, Hoyt	33.71	29.25	29.76	7.28	.53	6.79	42.52	.79	42.09	7,348
Utah										
Carbon, Sunnyside	5.96	38.68	48.77	6.59	1.73	5.43	71.28	1.52	13.45	12,841
Emery, Emery	3.93	40.92	49.22	5.93	.39	5.52	73.02	1.25	13.89	12,965
Iron, Cedar City	10.35	36.33	43.70	9.62	5.82	5.13	61.24	.95	17.24	10,874
Summit, Coalville	14.20	36.00	44.80	5.00	1.41	5.79	61.40	1.09	25.31	10,630

County Bed or Local Name	Proximate Analysis "As Received"				Ultimate Analysis "As Received"					Heating Value B.T.U. per Lb. "As Received"
	Moisture	Volatile Matter	Fixed Carbon	Ash	Sulphur	Hydrogen	Carbon	Nitrogen	Oxygen	
Virginia										
Henrico, Gayton	2.81	25.70	62.47	9.02	1.43	4.90	76.55	1.81	6.29	13,493
Lee, Darbyville	3.42	34.36	58.83	3.39	.58	5.25	77.98	1.29	11.51	14,134
Russell, Dante	2.76	34.96	56.51	5.77	.59	5.32	80.13	1.43	6.76	14,148
Tazewell, Pocahontas	3.50	15.50	76.80	4.20	.73	4.77	83.36	1.08	5.86	14,630
Wise, Georgel	2.48	31.71	60.30	5.51	.52	5.59	79.69	1.56	7.13	14,252
Washington										
King, Black Diamond	7.98	37.69	45.95	8.38	.45	5.60	64.79	1.69	19.09	11,732
King, Cumberland	5.84	31.32	36.46	26.38	.47	4.80	52.77	1.30	14.28	9,529
Kittitas, Roslyn	3.89	37.00	46.49	12.62	.37	5.58	68.55	1.31	11.57	12,434
Pierce, Carbonado	3.81	26.60	49.33	20.26	.39	5.01	63.85	1.93	8.56	11,518
Thurston, Centralia	25.08	32.25	34.02	8.65	.82	6.37	47.26	.91	35.99	8,170
West Virginia										
Fayette, Carlisle	4.95	18.16	73.75	3.14	.82	5.09	82.15	1.48	7.32	14,434
Fayette, Fayette	3.22	22.28	71.68	2.82	.55	5.11	83.07	1.56	6.89	14,702
Fayette, Hawks Nest	5.00	24.50	67.20	3.30	.55	5.12	80.06	1.38	9.59	14,280
Fayette, Kay Moor	3.17	25.11	68.81	2.91	.52	5.09	82.59	1.63	7.26	14,584
Fayette, MacDonald	3.22	17.53	76.46	2.79	.64	5.01	84.11	1.56	5.89	14,760
Fayette, Page	3.32	28.88	62.72	5.08	.80	5.29	79.73	1.37	7.73	14,209
Fayette, Sun	2.94	19.69	68.67	8.70	1.86	4.70	77.66	1.45	5.63	13,786
Logan, Holden	1.66	32.89	59.94	5.51	.93	5.16	78.97	1.26	8.17	14,126
M'Dowell, Ashland	2.80	14.50	77.40	5.33	.64	4.56	83.39	1.03	5.05	14,550
M'Dowell, Big Four	2.30	16.98	76.21	4.51	.66	4.36	85.00	1.20	4.27	14,636
M'Dowell, Coalwood	2.19	13.91	75.25	8.65	.57	4.45	80.69	1.19	4.45	13,995
M'Dowell, Eckman	3.32	16.22	76.35	4.11	.55	4.67	83.05	1.16	6.46	14,587
M'Dowell, Ennis	3.25	14.46	78.05	4.24	.48	4.65	84.05	1.12	5.46	14,571
M'Dowell, Powhatan	2.55	13.44	78.57	5.44	.57	4.58	83.60	1.01	4.80	14,569
M'Dowell, Roderfield	2.32	16.76	69.80	11.12	1.78	4.35	77.46	1.27	4.02	13,514
M'Dowell, Worth	3.00	13.00	78.80	5.23	.48	4.46	82.84	1.05	5.94	14,500
Marion, Monongah	2.95	35.01	56.44	5.60	.67	5.33	77.89	1.38	9.13	13,862
Mercer, Coaldale	3.43	14.58	77.89	4.10	.67	4.79	83.79	1.06	5.59	14,602
Mercer, Wenonah	3.58	13.17	79.10	4.15	.56	4.90	83.59	1.07	5.73	14,598
Monongalia, Richard	1.63	28.42	62.01	7.94	.96	5.00	78.24	1.28	6.58	13,937
Preston, Masontown	1.40	26.40	62.92	9.28	1.50	4.83	77.92	1.43	5.04	13,808
Raleigh, Sophia	3.30	14.00	77.60	5.14	.63	4.60	82.94	1.41	5.28	14,490
Raleigh, Stonewall	3.02	16.06	78.75	2.17	.80	5.02	85.02	1.40	5.59	15,001
Tucker, Thomas	1.12	20.74	70.38	7.76	1.05	4.52	81.22	1.59	3.86	13,800
Wyoming										
Bighorn, Cody	17.29	31.33	45.89	5.49	.35	5.64	59.15	.85	28.52	10,055
Carbon, Hanna	11.45	42.58	39.33	6.64	.38	5.27	59.66	.94	27.11	10,890
Fremont, Hudson	21.27	32.83	42.75	3.15	.89	6.13	55.91	.75	33.17	9,779
Hot Springs, Kirby	15.86	33.01	47.39	3.74	.59	6.06	62.03	1.29	26.29	10,984
Sweetwater, Superior	16.02	33.63	47.60	2.75	.94	6.11	62.29	1.08	26.83	10,849
Sheridan, Monarch	23.88	34.33	38.44	3.35	.38	6.29	54.07	1.14	34.77	9,335

SIZE OF COAL

While the heat value of any special grade of coal is the same whether the coal is large or small, the price of the finer grades is much less than that of the larger, but suitable appliances must be provided for burning them.

Anthracite is almost always sized, that is, screened. The commercial names of different sizes of coals are given in the following table. The coal of a stated size will pass through larger openings and over the smaller openings in a metal screen.

ANTHRACITE COAL SIZES—From *Steam*

	Round Mesh Screen Diam. of Holes in Inches		Standard Square Mesh Screen Size of Holes in Inches	
Trade Name	Passes through	Passes over	Passes through	Passes over
Broken	4½	3¼	4	2¾
Egg	3¼	2⅜	2¾	2
Stove	2⅜	1⅝	2	1⅜
Chestnut	1⅝	⅞	1⅜	¾
Pea	⅞	⅝	¾	½
No. 1 Buckwheat	⅝	⅜	½	¼
No. 2 Buckwheat (Rice)	⅜	$\frac{3}{16}$	¼	⅛
No. 3 Buckwheat (Barley)	$\frac{3}{16}$	$\frac{3}{32}$	⅛	$\frac{1}{16}$
Culm	Residue from screening.			

Despite the greatest care used in screening, some of the coal will be under size. This should never amount to more than 15%.

There is no classification for sizes of bituminous coals which holds good in all localities. The *American Society of Mechanical Engineers* suggests the following:

EASTERN BITUMINOUS COAL

(*a*) Run-of-mine; unscreened coal taken from the mine.

(*b*) Lump; coal passing over 1¼-in. mesh bar screen.

(*c*) Nut; coal passing through a 1¼-in. bar screen, and over ¾-in. bar screen.

(*d*) Slack; coal passing through a ¾-in. bar screen.

WESTERN BITUMINOUS COAL

(*e*) Run-of-mine, unscreened coal taken from the mine.

(*f*) Lump; this group is divided in several different ways, 6-inch, 3-inch and 1¼-inch lumps, according to the diameter of the circular openings over which the respective grades pass. They are also grouped as 6 x 3 inch and 3 x 1¼-inch lumps. The coal passes through the larger opening, and over the smaller.

(*g*) Nut; this is also divided into different sizes, 3-in. steam nut passes through a 3-in. diameter opening, and over a 1¼-in. opening. 1¼-in. passes through a 1¼-in. opening and over a ¾-in. opening. ¾-in. passes through a ¾-in. and over a ⅝-in. opening.

(*h*) Screenings; coal passing through 1¼-in. diameter opening.

APPRAISAL OF COAL

To determine with utmost accuracy the ash content and heating value of delivered coal would require the burning of the entire quantity and measurement of the heat liberated, or would require crushing the entire quantity and reducing it by an elaborate scheme of successive crushings, mixings and fractional selections to portions weighing approximately 1 gram. Both of these procedures are impracticable, although the first can be approximated where records of evaporation, CO_2, combustible in ash and flue gas temperature are available for calculating a heat balance.

The method actually employed is to select portions from all parts of a delivery of coal and to reduce systematically the gross sample thus obtained to the quantities required by the chemist. The gross samples should be so large that the chance of admixture of pieces of slate, bone, pyrites or other impurities in an otherwise representative sample will affect but slightly the final result. It can readily be seen that it is absolutely essential that the sample be representative of the whole quantity of coal from which it is taken. The accuracy and reliability of a coal analysis is dependent upon the method and care taken in obtaining the sample. This fact is so important that the *United States Government* in placing contracts for its coal purchases always gives in its specifications complete directions as to how the coal shall be sampled, as follows:

METHOD OF SAMPLING COAL DELIVERIES

(To be attached to and to become a part of the Specifications and Proposals issued by the Office of the................, for the purchase of coal for the fiscal year commencing July 1, 191.., and ending June 30, 191...)

NOTE.—As payment for bituminous and the steam sizes of anthracite coal is to be based upon the quality as shown by analyses of representative samples, it is imperative that every sample be collected and prepared carefully and conscientiously and in strict accordance with the method agreed upon herein, for if the sampling is improperly done, a determined price based on the analysis will be in error and it may be impossible or impracticable to take another sample; but if an analysis is in error, another analysis can easily be made of the original sample.

Gross samples of the quantities designated herein must be taken whether the delivery consists of a few tons or several hundred tons, because of the following cardinal principle in sampling coal that must be recognized and understood; that is, the effect of the chance inclusion or exclusion of too many or too few pieces of slate, or other impurities in what, or from what, would otherwise have been a representative sample will cause the analysis to be in error accordingly, regardless of the tonnage sampled. For example, the chance inclusion or exclusion of 10 pounds too much or too little of impurities in or from an otherwise representative sample of 100 pounds would cause the analysis to show an error in ash content and heating value of approximately 10 per cent., whereas for a 1,000-pound sample, the effect would be approximately only 1 per cent., the effect being the same whether the sample is collected from a 1-ton lot or from a lot consisting of several hundred tons.

1. **Time of Sampling.**—The coal shall be sampled when it is being loaded into or unloaded from railroad cars, ships, barges, or wagons, or when discharged from supply bins, or from industrial railway cars, or grab buckets, or from the coal-conveying equipment, as the case may be and as may be mutually agreed upon. If the coal is crushed as received, samples usually can be taken advantageously after the coal has passed through the crusher. Samples collected from the surface of coal in piles or bins, or in cars, ships, or barges, are generally unreliable.

2. **Size of Increments.**—To collect samples, a shovel or specially designed tool or mechanical means shall be used for taking equal portions or

increments. For slack or small sizes of anthracite, increments as small as 5 to 10 pounds may be taken, but for run-of-mine or lump coal the increments should be at least 10 to 30 pounds.

3. **Collection of Gross Sample.**—The increments shall be regularly and systematically collected, so that the entire quantity of coal sampled will be represented proportionately in the gross sample, and with such frequency that a gross sample of the required amount shall be collected. The standard gross sample shall not be less than 1,000 pounds, except that for slack coal and small sizes of anthracite in which the impurities do not exist in abnormal quantities or in pieces larger than ¾ inch, a gross sample of approximately 500 pounds shall be considered sufficient. If the coal contains an unusual amount of impurities, such as slate, and if the pieces of such impurities are very large, a gross sample of 1,500 pounds or more shall be collected. The gross sample should contain the same proportion of lump coal, fine coal, and impurities as is contained in the coal sampled. When coal is extremely lumpy it is best to break a proportional amount of the lumps before taking the various increments of a sample. Provision should be made for the preservation of the integrity of the sample.

4. **Quantity Represented.**—A gross sample shall be taken for each 500 tons or less, or in case of larger tonnages for such quantities as may be agreed upon.

5. **Preparation.**—After the gross sample has been collected, it shall be systematically crushed, mixed, and reduced in quantity to convenient size for transmittal to the laboratory. The sample may be crushed by hand or by any mechanical means, but under such conditions as shall prevent loss or the accidental admixture of foreign matter. Samples of the quantities indicated in Table 1 following shall be so crushed that no pieces of coal and impurities will be greater in any dimension, as judged by the eye, than specified for the sample before division into two approximately equal parts.

TABLE 1.—LARGEST SIZES OF COAL AND IMPURITIES ALLOWABLE IN SAMPLES RANGING FROM 1,000 TO 30 POUNDS IN WEIGHT.

Weight of sample to be divided, pounds	Largest size of coal and impurities allowable in sample before division
1,000 or more	1 inch.
500	¾ inch.
250	½ inch.
125	⅜ inch.
60	¼ inch.
30	$\frac{3}{16}$ inch, or 4-mesh screen.

The method of reducing by hand the quantity of coal in a gross sample shall be carried out as prescribed below, even should the initial size of the coal and impurities be less than Table 1.

6. **Hand Preparation.**—The progressive reduction in the weight of the sample to the quantities indicated in Table 1 shall be done by the following methods, which are shown on pages 18 and 19.

(*a*) **Mixing and Reduction by Discarding Alternate Shovelfuls.**—The alternate-shovel method of reducing the gross sample shall be repeated until the sample is reduced to approximately 250 pounds; and care shall be observed before each reduction in quantity that the sample has been crushed to the fineness prescribed in Table 1.

The crushed coal shall be shoveled into a conical pile (figs. 2 and 7) by depositing each shovelful of coal on top of the preceding one, and then formed into a long pile in the following manner:

The sampler shall take a shovelful of coal from the conical pile and spread it out in a straight line (figs. 3, *A*, and 8, *A*) having a width equal to the width of the shovel and a length of 5 to 10 feet. His next shovelful shall be spread directly over the top of the first shovelful, but in the opposite direction, and so on back and forth, the pile being occasionally flattened until all the coal has been formed into one long pile (figs. 3, *B*, and 8, *B*). The sampler shall then discard half of this pile, proceeding as follows:

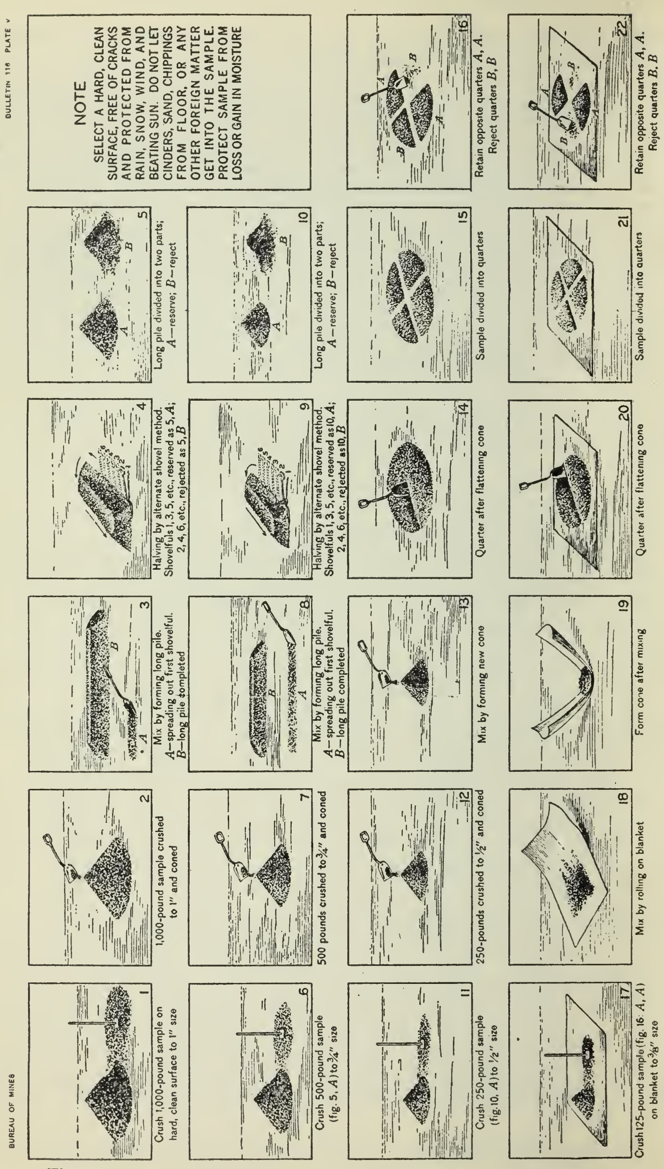
Beginning on one side of the pile, at either end, and shoveling from the bottom of the pile, the sampler shall take one shovelful (shovelful No. 1, figs. 4 and 9) and set it aside; advancing along the side of the pile a distance equal to the width of the shovel, he shall take a second shovelful (shovelful No. 2, figs. 4 and 9) and discard it; again advancing in the same direction one shovel width, he shall take a third shovelful (shovelful No. 3, figs. 4 and 9) and add it to the first. Shovelful No. 4 (figs. 4 and 9) is to be taken in a like manner and discarded, the fifth shovelful (No. 5, figs. 4 and 9) retained, and so on, the sampler advancing always in the same direction around the pile, so that its size will be gradually reduced in a uniform manner. When the pile is removed, about half of the original quantity of coal should be contained in the new pile formed by the alternate shovelfuls which have been retained (figs. 5, *A*, and 10, *A*, show the retained halves, and 5, *B*, and 10, *B*, the rejected halves).

(*b*) **Mixing and Reduction by Quartering.**—After the gross sample has been reduced by the above method to approximately 250 pounds, further reduction in quantity shall be by the quartering method. Before each quartering, the sample shall be crushed to the fineness prescribed in Table 1.

Quantities of 125 to 250 pounds shall be thoroughly mixed by coning and reconing (figs. 12 and 13); quantities less than 125 pounds shall be placed on a suitable cloth, measuring about 6 by 8 feet, mixed by raising first one end of the cloth and then the other (figs. 18, 24, and 30), so as to roll the coal back and forth, and after being thoroughly mixed shall be formed into a conical pile by gathering together the four corners of the cloth (figs. 19, 25, and 31). The quartering of the conical pile shall be done as follows:

The cone shall be flattened, its apex being pressed vertically down with a shovel or board, so that after the pile has been quartered each quarter will contain the material originally in it. The flattened mass, which shall be of uniform thickness and diameter, shall then be marked into quarters (figs. 14, 20, 26, and 32) by two lines that intersect at right angles directly under a point corresponding to the apex of the original cone. The diagonally opposite quarters (*B*, *B* in figs. 16, 22, 28, and 34) shall then be shoveled away and discarded and the space that they occupied brushed clean. The coal remaining shall be successively crushed, mixed, coned, and quartered until two opposite quarters shall equal approximately 10 pounds of $\frac{3}{16}$-inch or 4-mesh size. This 10-pound quantity shall be divided into two equal parts and each part shall be placed in a container suitable for transportation and shall bear an unbroken seal. One of the samples shall be forwarded by the officer in charge to the *Bureau of Mines*, Department of the Interior, for analysis, and the other shall be held in reserve by the officer in charge. Should the sample forwarded be lost or damaged in transit, then the reserve sample shall be forwarded.

7. **Mechanical Preparation.**—Only such mechanical means as will give



BUREAU OF MINES

BULLETIN 116 PLATE V

First stage

1 Crush 1,000-pound sample on hard, clean surface to 1" size

2 1,000-pound sample crushed to 1" and coned

3 Mix by forming long pile. *A*—spreading out first shovelful. *B*—long pile completed

4 Halving by alternate shovel method. Shovelfuls 1, 3, 5, etc., reserved as 5, *A*; 2, 4, 6, etc., rejected as 5, *B*

5 Long pile divided into two parts; *A*—reserve; *B*—reject

NOTE

SELECT A HARD, CLEAN SURFACE, FREE OF CRACKS AND PROTECTED FROM RAIN, SNOW, WIND, AND BEATING SUN. DO NOT LET CINDERS, SAND, CHIPPINGS FROM FLOOR, OR ANY OTHER FOREIGN MATTER GET INTO THE SAMPLE. PROTECT SAMPLE FROM LOSS OR GAIN IN MOISTURE

Second Stage

6 Crush 500-pound sample (fig. 5, *A*) to ¾" size

7 500 pounds crushed to ¾" and coned

8 Mix by forming long pile. *A*—spreading out first shovelful. *B*—long pile completed

9 Halving by alternate shovel method. Shovelfuls 1, 3, 5, etc., reserved as 10, *A*; 2, 4, 6, etc., rejected as 10, *B*

10 Long pile divided into two parts; *A*—reserve; *B*—reject

Third Stage

11 Crush 250-pound sample (fig. 10, *A*) to ½" size

12 250-pounds crushed to ½" and coned

13 Mix by forming new cone

14 Quarter after flattening cone

15 Sample divided into quarters

16 Retain opposite quarters *A*, *A*. Reject quarters *B*, *B*

Fourth Stage

17 Crush 125-pound sample (fig. 16, *A*, *A*) on blanket to ⅜" size

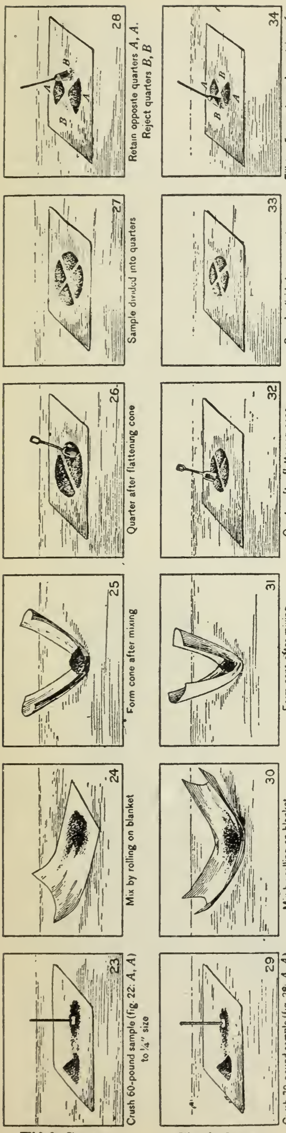
18 Mix by rolling on blanket

19 Form cone after mixing

20 Quarter after flattening cone

21 Sample divided into quarters

22 Retain opposite quarters *A*, *A*. Reject quarters *B*, *B*



Fifth Stage

Crush 60-pound sample (fig. 22: *A*, *A*) to ¼" size

Mix by rolling on blanket

Form cone after mixing

Quarter after flattening cone

Sample divided into quarters

Retain opposite quarters *A*, *A*. Reject quarters *B*, *B*

Sixth Stage

Crush 30-pound sample (fig. 28: *A*, *A*) to 3/16" or 4-mesh size

Mix by rolling on blanket

Form cone after mixing

Quarter after flattening cone

Sample divided into quarters

Fill two 5-pound sample containers from *A*, *A*, one for laboratory, one for reserve

METHOD OF PREPARING A SAMPLE OF COAL BY HAND. THE NECESSARY TOOLS ARE A SHOVEL, TAMPER, BLANKET MEASURING ABOUT 6 BY 8 FEET, BROOM, AND RAKE. THE COAL IS RAKED WHILE BEING CRUSHED, SO THAT ALL LUMPS WILL BE CRUSHED. FLOOR OR BLANKET IS SWEPT CLEAN OF DISCARDED COAL EACH TIME AFTER SAMPLE IS HALVED OR QUARTERED.

equally representative samples shall be used in substitution for the hand method of preparation herein specified.

8. **Extended Deliveries.**—For convenience, or if the accumulation of a sample would extend over any considerable period of time, the several quantities that would otherwise be combined to make up the gross sample may be worked down as collected and reduced to samples of a size suitable for transmittal to the laboratory, and these fractional samples may be analyzed and the several analyses averaged, or the several samples may later be mixed at the place of sampling or in the laboratory and reduced to one sample, one analysis being made. In the averaging of analyses or in the mixing of the several samples, weights shall be used proportionate to the tonnages which the fractional samples represent.

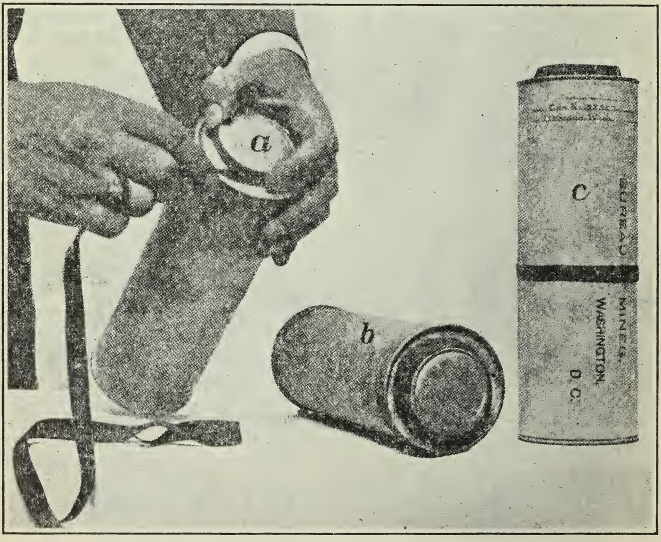
9. **Special Moisture Sample.**—In the reduction of the gross sample to the sample for transmittal to the laboratory, the gross sample may unavoidably lose moisture. To determine the moisture content in the coal delivered, a separate special moisture sample may be taken. This special moisture sample shall be taken so as to represent the coal with respect to the moisture contained at the time of weighing.

10. **Collection of Moisture Sample.**—The special moisture sample shall weigh approximately 100 pounds, and shall be accumulated by placing in a waterproof receptacle with a tight-fitting and waterproof lid small equal parts of the freshly taken increments of the gross sample, or they may be collected separately and independently of the gross sample. The accumulated moisture sample shall be rapidly crushed and reduced mechanically or by hand to about a 5-pound quantity, which shall be immediately placed in a container and sealed air-tight and forwarded to the laboratory. If prepared by hand, it shall be rapidly crushed so that no pieces of coal or impurities are larger than one-half inch, and it shall be rapidly reduced by the quartering method on a cloth to the 5-pound quantity.

11. **Moisture Samples Discretionary.**—The collection of special moisture samples shall be discretionary with the Government. If special moisture samples are not taken, the moisture determined for the gross sample shall govern, provided the gross sample shall be taken so as to represent the coal with respect to the moisture contained at the time of weighing, otherwise the moisture determination shall be waived.

12. **Moisture Sample May Represent Any Part of Delivery.**—A special moisture sample may be taken from any one railroad car or cars, or from a part of a delivery, if, in the opinion of the Government, said car or cars, or said part of a delivery contains moisture in excess of the amount guaranteed by the contractor, and should the moisture content of this special sample be in excess of the moisture content guaranteed by the contractor, then the Government shall have the right to make a deduction in price in accordance with paragraph 32 (*c*) under "Price and Payment," for the car or cars, or the part of the delivery sampled, and this correction shall in no wise affect the moisture correction for other railroad cars or parts of the delivery that may be sampled, or the correction that shall apply for variations of ash and heating value as determined for the delivery or order. The special moisture sample shall be used for no other purpose than for determining moisture content, and the moisture content so determined shall be considered as final.

13. **Sampling of 50 Tons or Less Discretionary.**—When orders are issued for 50 tons or less, sampling shall be discretionary with the Government; and if samples are not taken, the bid price per ton shall be paid.



METHOD USED BY *BUREAU OF MINES* FOR SEALING SHIPPING CAN WITH ADHESIVE TAPE.

The *Bureau of Mines* has developed a ladle to take the place of the shovel in sampling car shipments. This ladle is 1 foot in diameter at the top and 9 inches in diameter at the bottom. It is 9½ inches deep, and holds between 25 and 30 pounds. The handle is 5 feet long. In sampling shipments delivered from hopper cars, the ladle is rested on the rail, or on the chain that supports the car gates. Two ladlefuls are taken from each car, one on either side. The ladle is shifted if possible, to get coal from different parts of the stream. It can be used only where the discharge of the coal is not very rapid.

As wagons and railroad cars may arrive irregularly, and the coal be unloaded intermittently, a metal or wooden receptacle of a size to hold a gross sample of at least 1,000 pounds, with a tight-fitting lid which can be locked, is required. In sampling cargo deliveries, buckets holding from 60 to 70 pounds may prove more satisfactory, as the samples are usually worked down as the loading progresses. The buckets are convenient for carrying the coal to a place convenient for preparing the gross sample.

At the *State Capitol* power plant at *Madison, Wis.*, the coal is unloaded from the dump cars into a hopper and sent to a crusher. A sampler driven from one of the sprockets takes a scoopful of coal at regular intervals. This is deposited on a steel sampling board, about 100 pounds being taken from each car. The samples are crushed, mixed and quartered, the process being repeated until a composite sample of about 10 pounds remains, no piece larger than a filbert. From this sample four jars are filled and sealed for the laboratory, each marked with a serial number, and the car weight.

If the sample is properly crushed and mixed before placing in the cans and properly distributed in the cans, two laboratories should check well within 1%.

A mine sample analysis will usually indicate a better grade of coal as regards ash content and heat value than is determined by a sample from a commercial shipment. Different mines have different practices in regard to rejecting impurities. The moisture content will also be different. The calorific value of the delivered sample should be not more than 1% lower than the calorific value of the mine sample, provided there is not an excessive difference in the ash and sulphur. The ash variation should be less than 10% and the sulphur variation less than 3%.

PREPARATION OF LABORATORY SAMPLE

The proper preparation of the laboratory sample is as important as the proper taking and reducing of the gross sample of coal. The procedure at the *Bureau of Mines* laboratory is as follows:

The 5-lb. sample of coal in the air-tight can is all under ¼-in. in size. It is transferred from the can to a sheet metal pan and spread out to a depth of 1 in. This is weighed and placed in a large drying oven through which warm air is passed at a temperature of 30° to 35° C., until the loss in weight between weighings 6 to 12 hr. apart does not exceed ½%. The reduction in weight is called the "air-drying loss."

The sample is immediately crushed in a roll crusher to a 10-mesh size and reduced by a riffle sampler to a 500-gram quantity. This is put into an Abbe ball mill, which is sealed air-tight and rotated at about 60 rpm. Bituminous coals require ¼ to ½ hr., and anthracite 1 to 3 hr., to be reduced to a size to pass through a 60-mesh sieve. The 500 grams is then reduced to a 60-gram sample by successive halving in a small riffle sampler. This is then put through a 60-mesh sieve, and placed in a 4-oz. bottle with a rubber stopper. Large particles must be crushed by hand to force them through the sieve. 3 min. time in transferring the coal from the ball mill to the bottle should be ample. This is done as rapidly as possible, to eliminate moisture absorption.

It has been found that if a 4-oz. sample of fine coal containing heavy foreign matter in the form of slate, pyrites, etc., is allowed to stand, the heavy particles will tend to settle to the bottom. This tendency is more pronounced if the place of storage is subject to vibration, such as that caused by heavy machinery.

The pulverized samples should be very thoroughly mixed before the small amounts are taken for the actual analysis. The Fuel Inspection Laboratory of the *Bureau of Mines* is equipped with a mixing wheel on which the bottles are placed at 45°, and rotated at about 30 to 40 rpm. The wheel must not rotate so rapidly that the centrifugal force has an appreciable effect on the mixing.

The abrasion of the porcelain container and the flint pebbles in the ball mill is very slight. After 250 grindings, it was found that the pebbles showed a loss of weight equivalent to .004 of 1% of the coal that had been ground. After 100 grindings, the jar showed a loss of weight equivalent to 0.033% of the coal that had been ground. The total increase in the ash content was never raised more than .04 of 1%, which is less than the analytical error in the determination of ash.

The chemist's sample must have a composition that is an average of the entire lot of coal. "Skill and training are just as important in taking and reducing the samples as in making the chemical analysis."

The accuracy of any method of sampling should be tested frequently by taking and analyzing two samples independently.

In the power plant of the *Wisconsin Capitol*, the contents of one of the three-quart fruit jars is ground in a coffee mill, so that it will pass entirely through a 40-mesh sieve. If much work is to be done, a small roll crusher should be used. The sample is then quartered and reduced to a 4-oz. sample, which is put in a rubber-stoppered glass bottle bearing a number. This constitutes the laboratory sample.

Old pulverized samples cannot be regarded as representative. The *Bureau of Mines* took portions of the finely divided coal prepared for analysis and kept them in securely-stoppered bottles. They were weighed and analyzed from time to time over a period of a year. There was in every instance a gain of weight, and yet the moisture content usually decreased. The gain in weight is due to oxidation, and the moisture loss to actual loss by fixation in connection with the oxidation. In every case these changes were important. The smallest gain in weight was 0.53%, while one was 2.56%, with a decrease of 205 calories in the heat value. The change in weight corresponded to a decrease in heat value of 144 calories. The final calorific value therefore is 75 calories lower than accounted for by the change of weight.

The coal may change in moisture during the process of pulverization. In the *Bureau of Mines* laboratory it was found that samples ground on a bucking board would either gain or lose moisture, depending upon the thoroughness of the preliminary drying and upon the moisture content of the air of the laboratory. From this standpoint the method of grinding in a ball mill is much more satisfactory and reliable than any other, even though there is a slight change in moisture content during the grinding.

The moisture change in samples prepared and stored in different ways is quite great. A 1-gram sample of fine coal, previously undried, lost 2% in weight in 5 min., and 8% in 24 hr., when exposed to the air on a watch-glass.

Samples kept in an open bottle may lose considerable weight. One such sample lost 0.7% in 24 hr., 2% in 72 hr. and almost 5% in 24 days.

The loss in a well-dried sample is not nearly as large. A 1-gram sample lost 0.93% in 5 min., but after that the loss was very slight. This indicates the extreme sensitiveness of finely-ground coal to changes in moisture, and shows the need of placing the stopper tightly in the bottle.

After 72 days the 1-gram sample of coal previously undried had lost a decidedly greater percentage than the 10-gram sample of the same pulverized coal, and about twice as much as the sample in the open bottle. It is quite certain that the change in weight is not entirely due to moisture loss, but to oxidation as well.

PROXIMATE ANALYSIS

The true test of any coal is the burning of it. On the other hand, the chemical character and quality of a coal is a reliable indication of what may be expected from its use. Coal can be purchased under specifications as to the chemical content, and knowledge of the chemical content makes it possible to determine whether the coal specified has been delivered. In a large manufacturing plant coal and cinder analyses should be made daily. An average analysis for the month is obtained by multiplying each analysis by the number of cars it represents, and dividing the sum by the total number of cars. Analyses should be made by a careful and experienced person having proper facilities, as will be apparent from the following. There are two different kinds of coal analysis:

1. The proximate analysis determines the moisture, volatile matter, fixed carbon and ash as percentages. This information is sufficient for most uses.
2. The ultimate analysis is a chemical analysis giving the percentages of carbon (C), hydrogen (H), nitrogen (N), sulphur (S) and ash.

Sulphur is usually determined in connection with a proximate analysis, but is not given as a part of the 100%.

A determination of the heating value of a coal is nearly always made in connection with a proximate analysis, and usually in connection with an ultimate analysis, although the heat value can be very closely computed from the latter. The following definitions are used:

Fixed carbon is the carbon remaining after distillation. It is *not* the same as the total carbon found by ultimate analysis.

Combustible is arbitrarily defined as that portion of the dry coal left after subtracting ash and moisture.

Volatile matter is the total combustible less the fixed carbon, and includes gases, hydrocarbons, free oxygen and nitrogen, although the latter two are not combustible.

Ash is the residue remaining after the moisture and volatile have been driven off and the fixed carbon ignited.

Moisture is arbitrarily considered to be the loss in weight of a sample of coal when dried at a given temperature for a given length of time.

Different laboratories use somewhat different methods in making proximate analyses. The United States *Bureau of Mines* has probably made more analyses than the others put together, and has developed complete and satisfactory methods, which agree very closely with those recommended by the committee on coal analysis of the *American Chemical Society*. *Buréau of Mines* methods are given in what follows, except where otherwise noted.

For making a proximate analysis, the following apparatus is required: A mill for grinding the coal, chemical scales sensitive to 1/1000 of the amount weighed, drying apparatus, including an oven and a dessicator, a platinum crucible, a Bunsen burner and a blast lamp, and a supply of oxygen gas. The *Bureau of Mines* prefers sulphuric acid to calcium chloride as a moisture absorbent in the dessicator.

Moisture Determination.—The moisture loss occurring during the short time that a sample is usually allowed to stand in the laboratory appears unimportant. One sample standing for five days in a covered metal pail showed a loss of .49% moisture, from 5.07 to 4.58%.

It is impossible to reduce a sample without losing some of the moisture in the process. For this reason, a "total moisture" sample is to be taken immediately after the coal has been reduced to pass a 20-mesh sieve. Care must be used to regulate the temperature, if heat is used in drying. It must not be too low, lest all the moisture be not driven off, and it should not be too high, lest some of the volatile escape. The *Bureau of Mines* procedure in determining moisture is to weigh out 1 gram of the pulverized, air-dried sample, and place it in a shallow porcelain capsule, ⅞ in. deep and 1¾ in. in diameter. It is dried for one hour at 105° C. in a constant temperature oven, through which a current of preheated air is passing at a rate to change the entire volume of air 2 to 4 times per minute. The air is dried before entering the oven by passing through concentrated sulphuric acid. After 1 hr. the capsule is removed from the oven, and cooled in the dessicator. The loss in weight is called the "moisture at 105° C."

The drying oven at the *Bureau of Mines* laboratory is 10 in. wide and 13 in. high, built entirely of heavy sheet copper. It has four separate compartments, into each of which fits a drawer holding 12 capsules. Each compartment is surrounded by a bath of boiling glycerin (2 parts to 1 part water) and has an opening at the back for admitting chemically dried air. The bath is heated by 2 Bunsen burners through a coiled tube in the base of the oven. A return condenser at the top of the bath prevents concentration by distillation. The advantages of this type of oven are large capacity, uniform heating, little attention required, any compartment may be opened separately, trays are as completely surrounded by the bath as it is possible to make them, the glycerin solution boils at 248° F., and keeps the temperature at about 221° F., or 105° C. It requires 1½ hr. to dry the sample.

The size of the sample used in the moisture determination makes slight difference in the percentage determined. Samples ½, 1, 2 and 4 grams in size, after drying one hour, showed about the same moisture loss at 105° C. Practically all the moisture is expelled after ½ hr. of heating. The primary purpose of air-drying is to bring the sample to a condition of approximate equilibrium with the air in the laboratory.

The *American Society of Mechanical Engineers Power Test Code* procedure for moisture determination is as follows: Take one of the samples contained in the glass jars, subject it to a thorough air-drying by spreading in a thin layer and exposing for several hours to the atmosphere of a warm room, weighing it before and after, thereby determining the quantity of surface moisture which it contains.

Then crush the whole of it by running through an ordinary coffee mill or other crusher so adjusted as to produce somewhat coarse grains (less than $\frac{1}{16}$ in.) Thoroughly mix the crushed sample, select from it a portion of from 10 to 50 grams, weigh in a balance and dry it for one hour in an air or sand bath at a temperature between 240° and 280° F. (this temperature being necessary with coal which is not powdered). Weigh it and record the loss. Heat and weigh again until minimum weight has been reached. The difference between the original and the minimum weight is the moisture in the air-dried coal. The sum of the moisture thus found and the surface moisture is the total moisture.

If a large drying oven is available, the moisture can be determined by heating one of the glass jars full of coal, with the cover removed, at a temperature between 240° and 280° F., until it reaches the minimum weight. With certain lignites, lower temperatures for drying may be advisable.

The moisture contained in coal is in two conditions. The first is extraneous moisture, and is taken up from water percolating through the mine, from atmospheric precipitation, or from washing water. The relative amount depends largely upon the size of the coal. Slack coal retains 4 to 10 times as much superficial moisture as screened lump exposed to the same conditions. The remainder of the moisture is inherent in the coal. It is part of the original vegetable matter from which the coal was derived. The analysis does not distinguish between the two forms.

Mine samples contain little extraneous moisture, so that the determination shows closely the **inherent moisture.** Its amount is shown approximately by the following figures:

Eastern Appalachian bituminous coals, 2 to 4%.
Western Appalachian and Ohio coals, 4 to 10%.
Indiana, Illinois, Iowa and Missouri coals, 8 to 17%.
Sub-bituminous coals, 12 to 30%.
Lignite, 25 to 45%.

The moisture content is the distinguishing feature between sub-bituminous and lignite coals.

Volatile Matter Determination.—The objection has sometimes been made that the term "volatile matter" properly includes moisture. "Volatile combustible matter" would also be incorrect, as this would imply that all of the volatile matter exclusive of moisture was combustible, whereas it includes such non-combustibles as carbon-dioxide and nitrogen. From one-tenth to one-third of the volatile matter is non-combustible. A conservative estimate places the carbon in volatile matter at one-half by weight.

The volatile matter does not represent any definite compound in the coal. The method of determination is wholly conventional. The temperature at which the determination is made is very important, but differs in different laboratories, since they use different gases for heating. The following figures show the difference in the volatile as determined at different temperatures:

Effect of Temperature on Per Cent. Volatile Determination

Name of Coal	Temperature of Determination 750° C.	 1075° C.
Pittsburgh	33	34¾
Pocahontas	14¾	17¼
Anthracite	2¾	5¼
Coke	½	1¼

The *Bureau of Mines* method of determining volatile matter is as follows: One gram of the fine coal (that which passes through a 60-mesh) is weighed into a bright, well-burnished 10-gram platinum crucible, with a close fitting capsule cover. It is heated to 950° C. on a platinum or nichrome triangle for 7 min. in the full flame of a No. 3 Meker burner. The flame is 16 to 18 cm. long, and the bottom of the crucible is 2 cm. above the top of the burner. A sheet-iron chimney is placed around the burner to prevent draft. The temperature is measured by a thermocouple whose hot junction is buried in contact with the coal at the bottom of the crucible. After 7 min. the crucible is cooled in the dessicator and weighed. The loss in weight is the volatile plus moisture.

The 10 cc. platinum crucible is used in preference to the 30 cc. crucible formerly used, because the loss of weight due to oxidation of the carbon is thereby reduced from 1% to about 0.3%. The excessive loss was due to the fact that there was not sufficient volatile matter in a sample to expel the 30 cc. of air in the crucible when the heating was begun.

The Meker burner is superior to the Bunsen burner, especially for natural gas. The construction practically eliminates the fluctuating inner cone of the ordinary Bunsen flame, and thus affords a solid flame of fairly uniform temperature, which completely envelops the bottom and sides of the crucible.

Coal gas and water gas will readily produce a crucible temperature of 950° C. when supplied to a burner at a pressure of about 2 in. of water. From 950° to 1000° C. appears to be the proper temperature at which to make a volatile determination. Duplicate determinations within these limits usually agree within ½%.

The *Bureau of Mines* found that with several samples of coal it was impossible to duplicate volatile matter determinations by the method of heating for seven minutes at 950° C., which is for convenience termed the "official method." It was found that there was a mechanical loss due to the throwing out of solid particles by the rapid expulsion of volatile matter and that there was a different breaking down of the hydrocarbons when expelled under different conditions and in the presence of variable amounts of moisture. A modified method was developed whereby the sample was given a preliminary heating for 4 min. and then the regular 7 min. heating at full temperature.

The same coal was treated under both methods. That mechanical losses occurred during the rapid evolution of the volatile matter by the official method was indicated by the shower of solid carbon particles driven off as sparks. The average result for the official method was volatile matter 67.1%, ash 4.34%. For the modified method, volatile matter 36.35%, ash 11.15%. The moisture in the sample determined at this time was 19.78%, and the fixed carbon 32.72%. The difference in the ash report on the two tests was 6.81%, or the part of the ash driven off with carbon is 61%. Taking this proportion of the fixed carbon result by the modified method gives 20% as the amount of fixed carbon expelled mechanically in the official method. Correcting the result of the official method by this, would show the following analysis: Moisture 19.78, volatile 47.10, fixed carbon 21.97, ash 11.15. The analysis by the modified method would show moisture 19.78, volatile 36.35, fixed carbon 32.72. After making the correction for mechanical losses of fixed carbon, there is a difference of 10.75% between the two processes of determining volatile. This must be due to the difference in the breaking down of the hydrocarbon compounds by the different treatments.

Results show, at least for lignite, that the fineness of the sample has an important effect upon the volatile determination. The finer the particles the less the volatile showing. Tests on bituminous coals showed somewhat lower volatile results for the finer particles. This is probably due to the more complete sintering together of the fine samples on heating, with a consequent effect on the giving off of volatile.

When coals ranging from peat to anthracite were tested, and the volatile matter found both by the official and the modified method, it was found, with the exception of anthracite and semi-anthracite samples, that the results by the modified method all showed a considerably less amount of volatile matter and a correspondingly greater amount of fixed carbon. In all but the lignite the ash contents were about the same when the two methods were used, so that the difference is due to the breaking down of the hydrocarbons.

Air-dried coals were mixed with known amounts of water to ascertain what effect loosely-held moisture has on the volatile determination. By both methods, the volatile indicated was greater with the coals moistened. It appears that a rapid application of heat to drive off moisture results in a reaction between the water vapor and the carbon or hydrocarbon.

The conclusion is reached that the value obtained in the volatile determination is affected to an important degree by:

1. The method of heating;
2. The fineness of pulverization;
3. The amount of loosely-held moisture in the sample.

In bituminous coals, these differences do not exceed 3 or 4%, and therefore the official method is used. In lignites, the differences may run up to 25%, and so the modified method is used.

Ash Determination.—For determining ash the *Bureau of Mines* uses the same sample on which the moisture determination was made. It is left in the capsule and placed in a cool muffle. The temperature is gradually raised to 750° C., and the ignition is continued, with occasional stirring of the ash, until all the carbon particles have disappeared. The capsule is cooled in a dessicator, weighed, and the ignition repeated until a constant weight has been obtained. A constant weight is assumed to have been obtained when the difference between successive weighings is .0005 gram. The residue in the capsule represents ignited mineral residue, or "uncorrected ash."

For technical purposes, the uncorrected ash is reported as determined. The principal use of corrected ash values is in computing the actual coal substance or combustible matter of coal, for comparing ultimate analyses and heating values on this basis. Coal may contain calcium carbonate, iron carbonate or iron pyrites. These, together with the water of composition of the mineral substances, would be altered in composition by the ash determination as done above. *Parr* has suggested a method of correcting for these errors. At best the corrections are only approximations, and since the errors are small, they need not be considered in ordinary practice.

The *Bureau of Mines* furnace for ash determination is an ordinary assayer's furnace. It consists of a fire clay box, called a muffle, which the furnace gases do not enter, and so arranged that access may be had to it from an open end at the front. The muffle is supported in a combustion chamber formed of an iron-bound box lined with fire brick. The muffle is heated to cherry redness by means of a gas blast from a special burner projecting into the combustion chamber.

The *American Society of Mechanical Engineers Power Test Committee* recommends that the ash be determined upon the sample which has been used for determining the volatile. Expose the residue in the crucible to the blast lamp until it is completely burned, using a stream of oxygen, if desired, to hasten the process. The Committee Report also describes the *Bureau of Mines* method.

Fixed Carbon Determination.—The *Bureau of Mines* determines the fixed carbon by calculation, subtracting the sum of the percentages of moisture, ash and volatile matter from 100.

The *American Society of Mechanical Engineers Power Test Committee* says that the difference between the residue left after the expulsion of the volatile matter and the ash is the fixed carbon.

The fixed carbon does not represent all of the carbon in the coal, as a considerable part of the carbon will have been driven off in the volatile hydrocarbon. Neither is the fixed carbon pure carbon. In addition to the ash-forming constituents, there are several tenths percent. of hydrogen and oxygen, 0.4 to 1% of nitrogen and approximately half of the sulphur in the coal.

Sulphur Determination.—In connection with a proximate analysis, sulphur is usually determined. See the following section on Ultimate Analysis.

Apparatus Required.—The list of apparatus and estimated cost for making a proximate analysis and a heating value determination given below is from the *National Engineer.* This apparatus may be obtained from Eimer & Amend, New York, or E. H. Sargent & Co., of Chicago.

Emerson calorimeter with nickel lining, electric ignition and motor-driven stirrer	$180.00
Oxygen and tank	20.00
Beckman thermometer, graduated to 100° C.	35.00
Thermometer for oven	1.50
Analytical balance and weights sensitive to 1/10 milligram	60.00
Balance for weighing water, 5 kilos capacity	12.00
4 Bunsen burners at $1.25	5.00
2 ring stands at $0.75	1.50
2 dessicators at $1.25	2.50
1 dozen 1¼ in. covered porcelain crucibles	1.80
1 spatula	.15
1 mortar	.50
1 set sieves 20 to 100-mesh	1.50
2 crucible tongs at $0.75	1.50
1 coffee mill	1.00

Slight additions to this outfit will enable anyone to determine amount of sulphur in coal, test oil, water, etc., in short to do any ordinary chemical work about a steam plant. For description of the use of a calorimeter, see page 31.

ULTIMATE ANALYSIS

The items considered in an ultimate analysis are moisture, carbon, hydrogen, oxygen, sulphur, nitrogen and ash.

The oxygen is taken as 100% less the sum of the ash, sulphur, carbon, hydrogen and nitrogen. The error in the oxygen determination is the algebraic sum of the errors in all the other determinations.

An ultimate analysis does not distinguish between the carbon and hydrogen derived from the organic or combustible matter of the coal and the small proportion of these elements that may be present in an incombustible form in the mineral impurities. A correction is not necessary, as the error is small.

An ultimate analysis includes the hydrogen and oxygen of the moisture with the hydrogen and oxygen of the dry substance. Usually before comparisons are made, the ultimate analyses are computed to a dry coal basis, thus giving the relative proportions of hydrogen and oxygen in the coal after the moisture has been eliminated.

The apparatus required for an ultimate analysis comprises a mill or other apparatus for grinding or pulverizing the coal, chemical scales, drying apparatus, combustion apparatus embracing a combustion furnace, a glass combustion tube, one end of which is filled with copper oxide and chromate of lead and the other end with a roll of oxidized copper gauze, a porcelain boat, a set of bulbs containing hydrate of potassium, a U-tube filled with chloride of calcium, and a supply of pure oxygen and pure air, together with suitable chemicals and chemical apparatus required for the various processes.

Carbon and Hydrogen Determination.—The *Bureau of Mines* determines the hydrogen and carbon by the usual method of combustion in oxygen. 0.2 gram of air-dried coal is burned in a 25-burner Glaser furnace or Heraeus electric furnace. Complete oxidation is insured by passing the products of combustion over red-hot copper oxide. A layer of lead chromate follows the copper oxide to remove the sulphur. The water vapor and carbon dioxide are absorbed and weighed in previously-weighed calcium chloride and potassium hydroxide solutions respectively. No correction is made for the carbon or hydrogen from inorganic matter in the coal.

The *American Society of Mechanical Engineers Power Test Committee* says that carbon and hydrogen are obtained by the use of the combustion apparatus. ½ gram of the pulverized oven-dried coal is placed in a porcelain boat, which is introduced between the copper roll and the copper oxide within the combustion tube. After the contents within have been thoroughly dried out by a sufficient preliminary heating, aided by a current of dry air, the furnace is set to work and the coal burned by passing air through the tube, and then finally oxygen, conducting the products of combustion through the potash bulb and the chloride of calcium tube. The carbon dioxide is absorbed by the potash and the water from the combustion of hydrogen is taken up by the calcium chloride. The quantity of carbon dioxide, from which the carbon is determined, is ascertained from the weight of the bulb before and after the absorption. The quantity of hydrogen is determined by weighing the calcium tube before and after.

The assumption that all of the oxygen in the coal is combined with ⅛ of its weight of hydrogen as water is well supported in anthracite and bituminous coals by the agreement of the heat value computed by DuLong's formula with the actual bomb calorimeter determination. The remainder of the hydrogen is termed "available hydrogen."

Nitrogen Determination.—The *Bureau of Mines* uses the Kjeldahl-Gunning method. 1 gram of air-dried coal is digested with 30 cc. of concentrated sulphuric acid, ½ gram of metallic mercury and 5 grams of potassium sulphate, until the carbon has been completely oxidized and nitrogen converted to ammonium sulphate. After dilution with water and precipitation of the mercury by the addition of potassium sulphide, an excess of sodium hydroxide is added, and the ammonia is determined by distillation. For a complete description of this determination see Technical Paper No. 8.

The *American Society of Mechanical Engineers* says that to determine nitrogen a certain weight of coal is mixed with strong sulphuric acid and permanganate of potash, and heated until nearly colorless. This process converts the nitrogen into ammonia, and then into sulphate of ammonia. The amount of sulphate is determined by making the solution alkaline and then distilling it. The nitrogen is found by calculation from the known composition of ammonia. Recent experiments show that the nitrogen as thus found in coal is 0.2 to 0.3% too low, and that in order to obtain more accurate results it is necessary to add mercury and potassium sulphate.

Determination of Sulphur.—Sulphur occurs in coal in three forms:

1. As pyrite. This is its most common form in coal, and varies greatly in amount. In some coals the pyrite can be removed by picking or washing.
2. As sulphate of iron, calcium or aluminum. It may be found in this form in weathered coals. On exposure, pyrite tends to absorb oxygen, and to form sulphate. Sulphur as sulphate has no heating value.
3. In combination with coal substances of organic composition. This form is next to pyrite in prominence. Little is known about it.

Sulphur in the free state has been found in coal in rare instances.

Iron pyrite is heavy, crystalline and brass-like in color. Calcium sulphate or gypsum occurs in small, thin white flakes, more or less transparent.

If the ash contains no lime or alkali oxides, sulphur is distributed about half in the volatile and half in the fixed carbon.

The *Bureau of Mines* uses for sulphur determination the residue in the calorimeter after completing combustion in determining heat value. The crucible is washed out thoroughly and the washings collected in a 250 cc. beaker. The washings are titrated with a standard ammonium hydroxide solution to obtain the acid correction for the heat value. (See page 33.) 4 cc. of strong ammonium hydroxide are added to insure complete precipitation of any metals in solution, and the solution is heated to the boiling point on the hot plate. The residue, mostly ash, is filtered off, and washed five times with hot water, and 5 cc. of concentrated hydrochloric acid. A few drops of bromine water are added to the solution, which is replaced on the hot plate and heated to the boiling point.

Add 10 cc. of hot 10% barium chloride solution and allow the precipitate to settle for at least 2 hr. The supernatant liquid is decanted and tested with dilute sulphuric acid for an excess of barium chloride. The precipitated barium chloride is collected on a small filter paper and washed with hot water till the washings show no reaction for chloride. The filter paper, with the precipitate, is placed in a crucible, dried, ignited and weighed. The ignition is in a muffle for ten minutes. It is covered and cooled in a dessicator. The precipitate is then brushed onto a balanced watch glass and weighed. The sulphur in barium sulphate is $\frac{32.07}{233.44} = 0.137$ times the weight of the latter. The percentage of sulphur can easily be determined from the original weight of coal.

Eschka's method for sulphur determination is somewhat simpler and is used as a check by the *Bureau of Mines*. The *American Society of Mechanical Engineers* describes it as follows: A sample of the 60-mesh coal weighing 1.3736 grams is mixed in a 30 cc. platinum crucible with about 2 grams of Eschka mixture (2 parts light calcined magnesium oxide, 1 part anhydrous sodium carbonate) and about 1 gram of the Eschka mixture is spread over it as a cover. The mixture is carefully burned out over a gradually increasing alcohol or natural gas flame. When all black particles are burned out, the crucible is cooled, the contents digested with hot water, filtered, washed and the solution treated with saturated bromine water or hydrochloric acid, boiled, and the sulphur precipitated as barium sulphate by adding a solution of barium chloride.

Artificial gas should not be used for igniting the coal and Eschka's mixture, as the sulphur content of the gas will vitiate the results.

Moisture and Ash Determination.—The moisture determination for the ultimate analysis is the same as that described under proximate analysis. The ash is found by weighing the refuse left in the combustion boat after the coal is completely burned.

The ultimate analysis of coal, as will be seen from the above description, requires the use of so much chemical apparatus, and at best is so complicated, that it is not likely to be done except in a fully equipped chemical laboratory. It could not be undertaken by one who was not entirely familiar with all the details of the work.

The ultimate analysis is used in classifying coals (see Classification of Coals, p. 5). It is also used to calculate the heating value of a coal (see following pages) when a calorimetric determination has not been made. The sulphur determination is made in connection with a proximate analysis and is used to check up coal deliveries with specifications.

HEATING VALUE

The heating value, or calorific value, of a coal is the number of units of heat liberated by the perfect combustion of one unit weight of the coal.

A British Thermal Unit (BTU) is the quantity of heat required to raise the temperature of 1 lb. of water 1° F. (to be exact from 63° to 64° F.)

The gram calorie (small calorie) is the quantity of heat required to raise the temperature of 1 gram of water 1° C. at a mean temperature of 15° C.

The kilogram calorie (large calorie) is 1000 times the small calorie.

The necessity of knowing the heating value of the coal burned can be seen when we consider that the evaporation per pound of coal burned does not of itself indicate efficiency. An equivalent evaporation of 8 lbs. of water per pound of dry coal would represent 70½% efficiency if the coal contained 11,000 BTU per lb., but the same evaporation with a coal of 14,500 BTU heating value would represent only 53½% efficiency.

Two heating values must be considered for fuels containing hydrogen. The heating value found by the calorimeter is higher than that obtained under boiler conditions by an amount equal to the latent heat of vaporization of the water formed by the combustion of the hydrogen. These are called the higher and the lower heating values. The higher value, which is determined by the calorimeter, is the only scientific unit, and its use is recommended by the *American Society of Mechanical Engineers*.

There is no absolute measure of the lower heating value. It is an artificial unit, which involves the ultimate analysis and assumptions that make the unit impractical.

Hays says: "A heat value determination is an extremely difficult thing to make with accuracy. An ordinary laboratory should not be trusted, as it requires high-priced calorimeters and involves skill and experience. There are a great many calorimeters, some of which are not dependable within 500 BTU. There is no such thing as a calorimeter that anybody can use and be sure of accurate results."

The *Bureau of Mines* uses a bomb calorimeter with compressed oxygen. The temperature is read to 0.01° C. with the thermometer, and to 0.002° C. by a telescope and cathotometer. Corrections are made for radiation losses, oxidation of nitrogen to aqueous nitric acid, and oxidation of sulphur dioxide to aqueous sulphuric acid.

The bomb should be carefully standardized by burning substances of known calorific value. Standard samples of cane sugar, naphthalene and benzoic acid can be obtained from the *Bureau of Standards*. Calibrated thermometers are essential. In carefully conducted calorimetric work, the error should not exceed 0.3 of 1%. This degree of accuracy is higher than can be obtained with the usual methods of sampling.

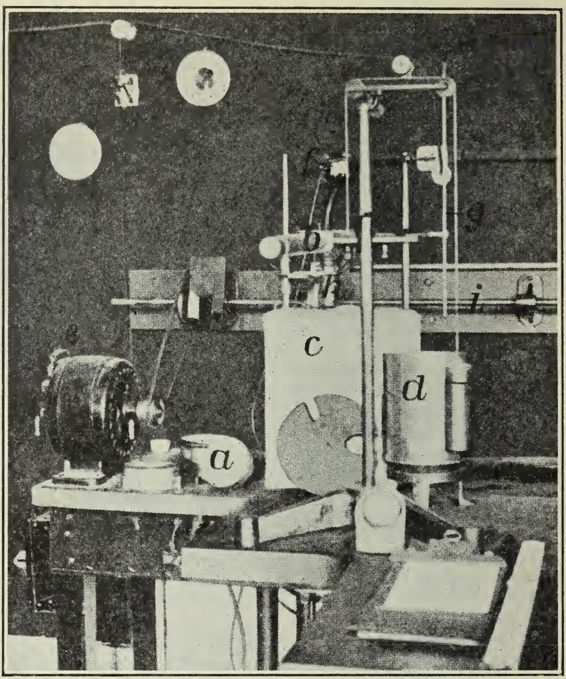
The requirements for a combustion calorimeter are as follows:

(*a*) That it shall effect complete combustion;

(*b*) That it shall allow no heat to escape absorption by the water;

(*c*) That its radiation and absorption factor shall be as small as possible, thus making the correction small;

(*d*) That the thermometer used for measuring the temperature difference shall be of the best quality and carefully calibrated.



BOMB CALORIMETER DISMOUNTED TO SHOW PARTS

One of the calorimeters used in the *Bureau of Mines* fuel inspection laboratory is shown in the photograph above. The calorimeter has been taken down to show its parts. The platinum-lined steel bomb is shown open at *a;* *b* is a cathotometer, magnifying power of about 55 diameters, used for observing the thermometer, which is shown removed from the calorimeter at *g*. By means of this instrument, the thermometer scale can be read accurately to 0.001° C. The calorimeter can *d*, containing exactly 1850 grams of distilled water and the charged bomb, fits inside the double-walled felt-lagged jacket *c;* *h* is a ball-stirrer of the propeller type driven at a constant speed of 1800 rpm. by means of a friction pulley and rubber band from the shaft *i;* *f* is an electric thermometer tapper controlled by means of a push button at the operator's table; *e* is a ½ H.P. electric motor that runs at a practically constant speed of 500 rpm. This motor, belted to the shaft as shown, serves to drive the stirrers of four calorimeters.

The *Bureau of Mines* procedure is to weigh 1 gram of coal into a platinum tray, which is placed on the support inside of the bomb. The platinum fuse wires are attached to the electrodes and dipped into the coal. The bomb cap is seated on a lead gasket, and oxygen put in at 350 lbs. per sq. in. pressure. The bomb is placed in the can containing a known weight of water. The whole is put in place in the jacket, the thermometer and stirrer inserted, and the jacket covered.

The temperature is observed at 1 minute intervals for 5 consecutive minutes. At the end of the fifth minute the circuit is closed. The thermometer is observed carefully and readings noted for two one-half minute intervals, and then for three one-minute intervals. The maximum temperature will have been reached, and the readings are taken for five minutes to determine the rate of gain or loss of heat.

There are two corrections to be made to the calorimeter result:

(*a*) The nitrogen in the coal will burn to nitric acid, which does not occur in the furnace. The acid correction is obtained by titration of the washings of the bomb with a standard alkali of such a strength that 1 cc. equals 5 calories, or 9 BTU.

(*b*) The sulphur content of the coal will burn to the SO_3 acid, instead of the SO_2 acid as in furnace combustion. A correction must be made for this difference. The sulphur from the ultimate analysis is used for calculating the correction.

The water equivalent of the calorimeter must be accurately known. The water equivalent is the heat capacity of the apparatus referred to water as unity. It is the sum of the products of the weights of the parts by their several specific heats. The following methods are used for determining it:

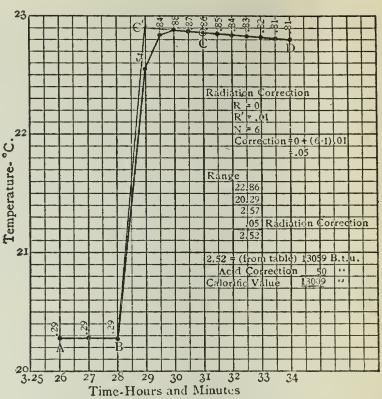
1. By weighing the parts and adding the products of the weights by the specific heats.
2. By burning in the calorimeter the same weight of a given substance, but using different amounts of water; two equations may be written involving two unknowns, namely, the water equivalent and the heating value of the substance.
3. By introducing electrically into the calorimetric system a known amount of heat.
4. By the well-known method of mixtures.
5. By burning in the calorimeter a known weight of a substance, the heating value of which is accurately known, and calculating the water equivalent by the heat difference.

The latter is most used by the *Bureau of Mines* laboratory, by reason of its ready application. The *Bureau of Standards* can supply standard sucrose for the purpose.

The temperature of the weighed water in a calorimeter is made by some experimenters slightly greater than room temperature, in order that the initial correction for radiation may be in the same direction as the final correction. Other experimenters start with the temperature of the water the same or slightly lower than the room temperature, on the basis that the temperature after combustion will be slightly higher than room temperature, and that the radiation correction will be a minimum, or entirely eliminated. While no experiments have been made to show which method is the better, the latter is generally used.

Before igniting the coal, take the temperature readings every minute to insure constant rate of change. The temperature at the instant the circuit is closed is the temperature at the beginning of combustion. After ignition, take the temperature reading every half minute for five minutes, and every minute thereafter for five minutes. Plot the thermometer readings against time, as in the chart on page 34.

The most accurate method of correcting for radiation is probably *Pfaundler's*, a modification of *Regnault's*. They are in practical agreement, and *Pfaundler's* is more simple. It assumes that in starting with an initial rate of radiation and ending with a final rate, the rates at intermediate temperatures are proportional to the initial and final rates, that is, the rate of radiation at a point midway between the temperature of ignition and the temperature at which combustion is presumably completed will be the mean of the initial and final rate. The rate at a point three-quarters of the distance on the curve between the two temperatures will be the rate at the lower or initial rate plus three-quarters the difference between the initial and final rate. Regnault assumes the radiation to be in each case proportional to the difference in temperature between the water in the calorimeter and the surrounding air, plus a constant found for each experiment.



GRAPHIC METHOD OF RECORDING BOMB CALORIMETER RESULTS

E. H. Peabody has devised a simpler formula than Pfaundler's, which under proper conditions gives a result which varies but slightly from Pfaundler's result. He noted throughout an extended series of calorimeter tests that the maximum temperature was reached by the thermometer slightly over one minute after the time of firing. If it were exactly one minute, the radiation would be the radiation for one-half minute before firing plus the radiation for ½ minute after the maximum temperature were reached.

$$C = \frac{M}{2} R + \left(N - \frac{M}{2} \right) R'$$

C = correction in degs. C.
N = number of time intervals over which the correction is made.
R = initial radiation in degrees per interval.
R′ = final radiation in degrees per interval.
M = number of time intervals between the time of firing and the maximum temperature.

In Peabody's case, deduction showed M=2, and

$$C = R + (N-1) R'.$$

Peabody's formula should not be used in cases where the point of maximum temperature is more than five minutes later than the point of firing. This approximate formula gives results within .003° F. for the limits of application as above. M, which is not necessarily a whole number, should be determined for each case, though it is probably constant for any individual calorimeter.

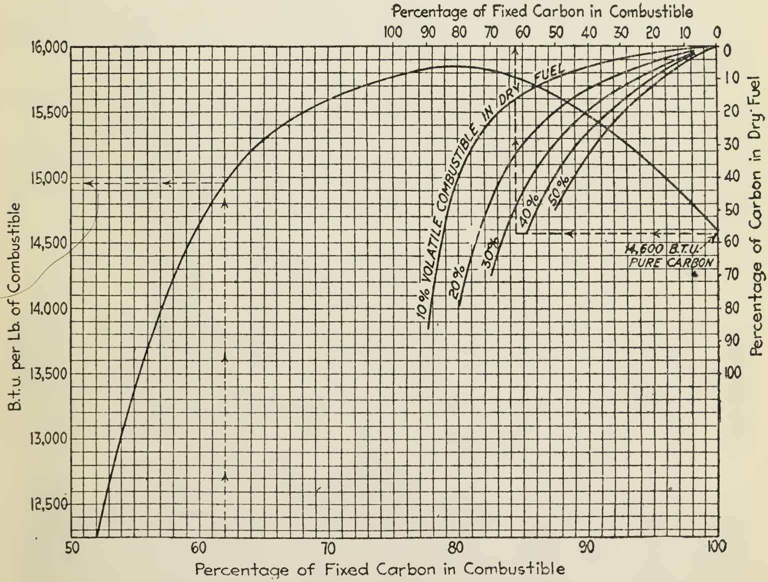
The heat value is determined as follows: Add the temperature which corresponds to the radiation correction to the range of temperature between the firing point and the point chosen from which the final radiation was calculated. Multiply this corrected range by the water equivalent of the calorimeter, including water and parts. The result is the heat of combustion of the weight of coal burned, plus the heat evolved by the burning of the fuse wire. Correction must be made for the fuse wire, for the nitric acid and for the sulphuric acid formed.

For the fuse wire correction multiply the actual weight in milligrams of iron fuse wire by 1.7, which is the number of calories per milligram. The result is in gram-calories.

The bomb is carefully washed with water. The washings are titrated with standard ammonia solution (containing .00587 gm. per cc.), methyl orange being used as an indicator. One cc. of this solution is equivalent to .00483 gm. of nitrogen, which burned to nitrogen pentoxide (N_2O_5) plus water generates 5 calories. Under a boiler the sulphur of coal burns to SO_2, whereas in the bomb it burns to SO_3 with the liberation of a greater amount of heat. One cc. of the ammonia solution is equivalent to .0055 gm. of sulphur or 12.1 calories more than if the combustion were to SO_2. Assuming each cc. of solution means a correction of 5 calories, a further correction of 7.1 (12.1–5) calories must be made for each .0055 gm. of sulphur, or 13 calories per .01 gm. of sulphur in the coal.

The total correction for aqueous nitric and sulphuric acids is found by multiplying the cubic centimeters of the standard ammonia solution by 5 and adding 13 calories for each .01 gm. of sulphur in the coal.

Heating Value from Analysis.—*Kent* deduced from *Moller's* tests a curve of the relation of the heating value to the percentage of fixed carbon in the total combustible as given in the proximate analysis. It is correct within close limits for fuels containing more than 60% fixed carbon in the combustible. Below that point there is an error reaching 4%. The chart below showing this relation is due to *W. C. Stripe.*



RELATION BETWEEN FIXED CARBON AND THERMAL VALUE. THE % FIXED CARBON IN THE COMBUSTIBLE FOR COALS OF DIFFERENT VOLATILE CONTENT IS OBTAINED FROM THE % CARBON IN THE FUEL BY USE OF THE CURVES IN THE UPPER CORNER OF THE DIAGRAM.

The ultimate analysis can be used to compute the heating value of a coal by substitution in *DuLong's* formula, which is

$$\text{BTU per lb. of coal} = 14{,}544C + 62{,}028\left(H - \frac{O}{8}\right) + 4050S$$

wherein C, H, O and S are the fractions of carbon, hydrogen, oxygen and sulphur respectively, in the combustible.

There are several objections to this method of obtaining the heating value of coal.

1. The heating value of the elements hydrogen, carbon and sulphur have not been established with any great degree of accuracy.

2. The heating value of elements in a free state and as component parts of a chemical compound are not necessarily the same. They usually vary, due to absorption or evolution of heat in the forming of the compound.

3. The assumption that all of the hydrogen is combined with the oxygen is not true.

4. The relative accuracy is subject to the uncertainty of the oxygen determination.

Also the cost of making the ultimate analysis is high.

In low-grade Western fuels, about two-thirds of the oxygen is in combination with carbon. For such coals, DuLong's formula would give heat values too low by assuming that all the oxygen is in combination with hydrogen.

The chart on page 37, published in *Power*, is plotted from DuLong's formula. It gives results as accurate as those given by calculations.

The calorific value of coal, ash-free and moisture-free, is equal to the calorific value as determined in the calorimeter divided by one minus the sum of the moisture and ash. This is found to be fairly constant for the same coal bed in adjacent mines. The greatest deviation in any mine is less than 1%.

ASH AND CLINKER

The ash in a coal may be considered to come from two different sources: first, substances derived from the original vegetable material, and second, those deposited either during the laying down of the coal bed or subsequently, such as particles of clay, sand or shale. These cannot be separated from the coal by any commercial method. A third source includes extraneous impurities, those becoming mechanically mixed with the coal during the mining. Washing, screening and picking are used to remove them.

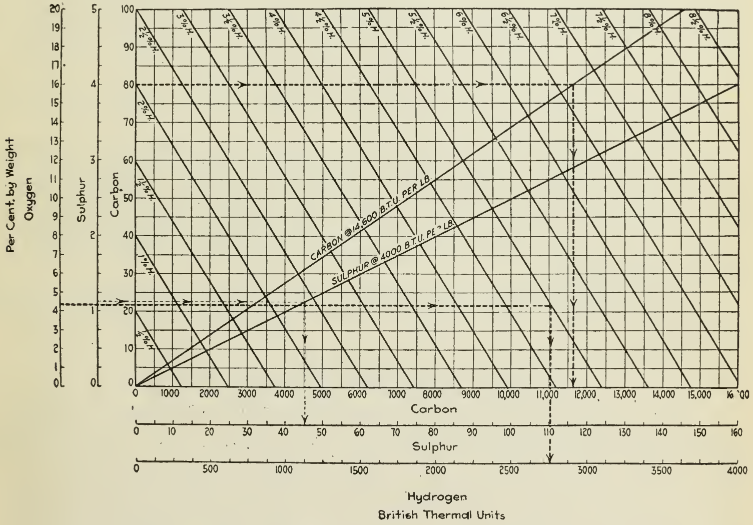
Ash is a mechanical mixture of silicates, oxides and sulphates, in which the percentages of the different constituents vary greatly. The silicates, however, predominate, in most cases. Coal ash is composed largely of silica (SiO_2), oxide of aluminum (Al_2O_3), oxide of iron, either as FeO or Fe_2O_3, oxide of lime (CaO), and oxide of sulphur (SO_2). It also contains small percentages of oxide of magnesium (MgO), oxide of sodium (Na_2O) and oxide of potassium (K_2O).

The table below gives an idea of the percentages of each of the constituents:

Coal	Total Ash, %	SiO_2	Al_2O_3	Fe_2O_3	CaO	SO_2	MgO	K_2O	Na_2O
		Constituents of Ash expressed as per cent. of Total Ash							
Anthracite	7.26	25.66	27.03	42.83	1.56	.17	11.83		
Semi-bit.	7.50	54.80	29.20	6.80	1.40	1.00	.60	2.10	1.90
Bituminous	17.40	47.30	34.60	9.80	1.20	.10	.40	2.50	2.10
Bituminous	8.20	15.20	8.60	13.30	18.10	26.90	10.00	1.80	5.30
Bit. Slack	11.40	53.20	26.00	15.80	1.00	.40	.70	1.60	.30
Lignite	16.60	39.30	24.08	3.80	14.90	12.50	1.70	.40	.10

Clinker is formed by the mechanical adhesion of the particles of ash, or by the fusing of the ash, thereby forming slag. An ash having a fusing temperature above 2700° F. will rarely give trouble if the coal is properly fired.

Clinker is of two types, hard clinker and soft clinker. Hard clinker is formed by the direct melting of the ash, or of some of its constituents. It hardens while in the ash on the grates. If formed by a portion of the ash melting, it will be in the form of a large hard cake at some point on the grate. If formed through certain constituents in the ash melting, it will be found as a number of small hard clinkers distributed throughout the ash. The caked hard clinker is usually the direct result of bad firing methods. The ash next



DU LONG'S FORMULA FOR HEAT VALUE OF COAL.

Assume a coal having the following ultimate analysis: Carbon, 79.90%; hydrogen, 4.98%; oxygen, 4.31%; nitrogen, 1.85%; sulphur, 1.13%; ash, 7.83%; moisture, 2.91%. The upper arrowed line shows that the carbon represents approximately 11,660 BTU. The lower heavy dotted line shows that approximately 2,750 BTU must be added for the 4.98% hydrogen, when 4.31% oxygen is present. The light dotted line shows that approximately 45 BTU will be obtained from the 1.13% sulphur. The summation of these three values gives 14,455 BTU as the total approximate thermal value of this fuel. Calorimeter tests on coal of the foregoing analysis have shown a value of 14,380 BTU, hence the results obtained graphically are satisfactory.

to the grate is considerably cooler than the burning coal in the fire bed, so that an ash that will not fuse when next to the grate will fuse when raised into the burning coal of the fire bed. Once melted, it runs down, is cooled and hardened, cementing pieces of coal and ash together. Small hard clinkers are formed by the fusing of certain ingredients of the ash. Usually they do not cause serious trouble. Any working of the fuel bed tends to cause partially melted or softened particles of ash to adhere to one another and thus to produce clinker.

Soft clinker remains molten while on the grates, but hardens when its temperature is sufficiently reduced. Once formed, the soft clinker continues to grow in size, until practically the entire grate is covered. It is formed by the slagging of the ash. It is not directly chargeable to bad methods of firing, although this may start the formation and hasten its spread. Soft clinker may have a consistency varying from that of a thick paste to that of a very heavy oil. The more fluid clinker is, the more troublesome, because it spreads faster. When first formed, a soft clinker is similar in appearance to a hard clinker. Inspection shows that it has a crust on the upper surface, underneath which it is fluid. Soft clinker is formed by the silica of the ash combining with the base that has the lowest fusing temperature. Once formed, the silicate dissolves both the silica and the base, and in this way grows in extent. Silica is infusible at ordinary temperatures. The basic oxides of the ash are refractory materials, and are quite infusible at furnace temperatures. However, they act as fluxes for the silica, and promote the fusing. The silica acts as an acid flux, whereas the oxide acts as a basic flux.

Before the subject of clinkering can be put upon a satisfactory basis, two kinds of measurement are necessary:

(*a*) The determination of the extent to which the clinkering of a given coal is objectionable in actual use. The important factor is not so much the total volume or weight of clinker formed as the kind of clinker. Large amounts of non-adherent clinker are not particularly objectionable, while small amounts of clinker which form pasty masses give much trouble. Probably the only reliable basis at present for determining objectionableness is the judgment of the fire-room observer.

(*b*) The determination by laboratory test of some characteristic of the ash which indicates the probable degree and objectionableness of the clinkering.

FUSING TEMPERATURE OF ASH

There is no definitely-known, invariable relation between the chemical composition of ash and the fusing point. The only kind of a laboratory test of real value is one that will show the melting point of ash. The melting point cannot be judged from the chemical analysis. In most ash, SiO_2 predominates, and therefore the fusing temperature decreases as the percentage of lime and iron increases, but in view of the large number of factors affecting the chemical composition of coal ash, no close estimate of the fusing temperature can be made from the analysis.

J. P. Sparrow says that, as a result of thirteen different coal tests in a Taylor stoker, the critical point of ash fusion lies between 2400° and 2500° F. Fusion temperatures above 2500° can be classed as non-clinkering, those below 2400° as clinkering. Using 2450° as a standard, there is an allowable variation of 50° above or below this standard to cover possible errors in testing.

Palmenburg's tests showed:

(*a*) An ash containing less than 10% Fe_2O_3 does not fuse at a temperature below 2550° F. An ash containing more than 20% Fe_2O_3 does not fuse at a temperature above 2550° F. An ash containing between 10 and 20% Fe_2O_3 has a fusing temperature which varies widely.

(*b*) Coals containing less than 1% sulphur do not fuse at a temperature below 2550°. A coal containing more than 2% sulphur does not fuse at a temperature above 2550° F. Coal containing between 1% and 2% sulphur has an ash fusing temperature which varies widely. (This rule is very crude, as there are many coals containing only 0.6% sulphur that have melting points at about 2150° F.)

(*c*) A coal containing less than 3% Fe_2O_3 plus sulphur does not fuse below 2550°. A coal containing more than 3% has an ash that does not fuse above 2550° F.

Cosgrove suggests as the surest method of determining whether a coal will clinker, trying it out in the furnace in which it is to be burned. If this is not practicable, the melting temperature of the ash may be determined experimentally by means of Seger cones, as follows: Moisten the powdered ash with a 10% solution of dextrine. Work into a stiff paste, and mould into pyramids of the standard form and dimensions of a Seger cone. Several Seger cones that will give the desired range of temperature, both below and above the probable formation temperature of the slag, are placed in a suitable heating oven with the cones of the ash, and slowly heated. The temperature should be increased slowly, at a rate of about 3.6° F. per minute, as the rise of temperature has considerable effect upon the melting temperature of the cones. By comparing the Seger cones at the instant when the ash cones have fused, the temperature represented by the Seger cone nearest the standard final form should be taken as the formation or fusing temperature of the ash. The standard form of a fused Seger cone is that when the top has bent over and touched a horizontal line called the base. The ash cone must be of the same size and form as the Seger cone.

Seger cones are three-sided pyramids. Nos. 22 to 25 are 3 in. high, with a base $\frac{5}{8}$ in. wide. Nos. 26 to 36 are $\frac{25}{32}$ in. high, with a base $\frac{3}{8}$ in. wide. The Seger cone of the lowest number always melts down first, the others following in their respective order, according to number. The number of each cone is found on its side.

Marks says that it is very important that complete incineration of the ash be accomplished before it is made into a cone. An appreciable amount of carbon tends to increase the apparent fusing temperature.

Fieldner, Hall and Feild made comparative tests on eighteen types of coal ash, in six different furnaces, showing that the fusing temperature was influenced by:

1. Shape and size of the Seger cone;
2. Inclination of the cone;
3. The fineness of the ash;
4. Rate of heating;
5. Nature of the atmosphere, whether oxidizing or reducing.

The latter has by far the greater influence, as much as 400° C. in some cases. The highest results were obtained in air with no reducing gases, or in a strong reducing atmosphere, whereby iron oxides were reduced to metallic iron. The lowest results were obtained in an atmosphere such that the iron oxide was reduced to the ferrous form, but not to the metallic state.

Marks points out that a determination of the melting point of coal ash is attended with many difficulties, the chief of which is due to the definition of the melting temperature. A satisfactory laboratory test for clinkering should indicate viscosity as well as the melting temperature of the ash. The only method used to any extent is an imperfect method of determining the temperature at which the material has a standard viscosity. The material is heated in the form of a Seger cone of standard dimensions, at a standard rate, until it is bent to some standardized final form. The cone has usually been set vertically. The rise of temperature is kept at the rate of 2° C. per minute. The melting temperature has been considered that at which the tip of the cone touches the plane of the base. This really only gives a standard viscosity when the time of bending is the same in all cases. The temperature increases as the bending goes on. It has been found that it requires from 10 to 80 min. for the cone to reach its standard form. The final viscosities are therefore obviously very different. In ashes where most fusible constituents are very fluid, the cones never come to the standard form, but merely decrease in height, flattening out instead of bending over.

Even if this did give the standard viscosity, it would not necessarily give information of any value on clinkering. It has not been shown that there is a lower limit of viscosity which cannot be passed without trouble from clinkering.

Sparrow places the cones horizontally, with the apex projecting over the side of the support. The method is more sensitive, and gives indications which can be duplicated more accurately and are therefore more reliable. The temperatures noted are at the beginning of bending, and when the apex of the cone points vertically downward.

There is a great diversity of results of fusing temperatures of ash obtained in different laboratories. One reason is the difference in the definition of the melting temperature. *Marks* mentions the following factors apparently affecting the melting temperature:

(*a*) Nature of the atmosphere. In tests with a Hoskins carbon resistance furnace, which has a reducing atmosphere, and a Meker furnace, which had an oxidizing atmosphere, the oxidizing atmosphere gave 120° to 255° F. lower temperature than the reducing atmosphere. The order of fusibility was changed. The lower the fusing temperature in an oxidizing atmosphere the higher the temperature in a reducing atmosphere. There is no question as to which should be accepted. At the lower and hotter part of the fuel bed there is always an oxidizing atmosphere.

(*b*) Size of Seger cone. The size of the cone has an influence which is different for different materials. With standard Seger cones, the difference is negligible. A No. 16 Seger cone (17 mm. base, 70 mm. high) had a horizontal melting temperature (initial to final bending) of 1355° to 1410° C. The same ash in a standard Seger cone (8 mm. base, 30 mm. high) had a horizontal melting temperature of 1355° to 1420° C. *Marks* adopted a cone having a base 11 mm. and the height 52 mm. Larger cones show a slightly lower melting temperature.

(*c*) Position of cone. The melting temperature of a horizontal cone is always less than that of the vertical cone.

(*d*) Nature of binder. The binder is usually a 10% solution of dextrine. It was found that water alone was satisfactory, if the cones were not dried much before putting into the furnace. The effect of adding dextrine is generally negligible, but sometimes it increases the apparent fusing temperature by as much as 10° C.

(*e*) Rate of heating cone. The rate of heating has a marked effect upon the fusion temperature. Any increase in the rate results in an increased lag of the pyrometer, and causes an apparent decrease in the melting temperature.

Tests with an increase of 6° C. per min. showed 35° to 40° lower melting temperature than did tests with the 2° per minute increase.

(*f*) Location of cone. This is very important; it should be as close to the pyrometer element as possible. 20° C. difference between the front and rear of a No. 29 Meker furnace was discovered.

(*g*) Support of the cone. The cone must be on a material unaffected by the highest temperature reached, and which does not react chemically with the ash cone. Plates of fused quartz are satisfactory. They must be so supported that the gases have a free circulation beneath.

To ascertain the possible relation between laboratory tests and clinker troubles, tests were run on ten coals at the Boston Edison plant, using Murphy stokers. It appeared probable that a final fusing temperature below 2462° F. indicates a coal that would give clinker trouble, and that a temperature above 2588° F. indicates a coal which would not give clinker trouble. From the point of view of the coal specifications, an important discovery was made, that the regular plant coal, which gave little clinker trouble, would have been rejected in coal specifications based on the fusing temperature alone.

The cone method failed in one respect. Cones of ash which gave most trouble had a very fluid constituent, which ran down and dropped off the tip of the cone. The infusible constituents were left, and the cone did not bend until their higher fusing temperature was reached. The least fusible constituent will not bend until its own fusing temperature is reached.

It is possible to accept the appearance of the bent cone as partial indication of the clinker behavior, and it may be possible to predict the behavior of the ash from that indication, combined with the fusing temperature. The appearance of the cone is more valuable, however, than the range of fusing temperature.

THE VALUE OF COAL FOR STEAM PURPOSES

In determining the value of a coal, the terms efficiency, economy and capacity may become confused. A study of the coals available may show the advantage of using a low-priced coal that gives 65% furnace and boiler efficiency, as against a higher-priced coal that gives 75% efficiency. The efficiency of the dollar is the criterion. An increase in capacity at a sacrifice of efficiency may make for economy, by saving fixed charges on additional boilers and equipment.

In determining the actual cost of coal, include the price delivered at the generating station, the cost of unloading into the bunker, the cost of moving from the bunker to the fire, the cost of removing and disposing of the ash, and the interest on the capital tied up in the reserve fuel supply.

Gould says that variations in quality equal to 10 or 15 cents per ton can occur without being noticed and reported by the fireman, and that figures prove that big variations in value are occurring every day in the coal delivered. It is human nature for a dealer to see that his better coal goes to the buyer who has the facts.

Since the smaller sizes of steam anthracite sell at lower prices, it is important to use the smallest size of anthracite possible. The equipment of a plant determines the size to use, but it is important to see that the size ordered is received. If 50% of the coal is undersized, you are losing not only the difference in the market price, but are losing too much through the grates. Bituminous and semi-bituminous coals vary in value even more than anthracite.

It is possible for several coals to show the same calorific value in the calorimeter and yet differ as much as 3 or 4% in actual commercial value as steam producers. It is advisable to have the laboratory fuel test supplemented by data obtained by measurements of fuel consumed and water evaporated.

G. C. Cook suggests as the factors to be considered in selecting a coal: the market conditions, the character and type of boiler-room equipment, the load and service requirements, the boiler-room personnel and the requirements as to smoke. Careful investigation should be made to ascertain the ability of the dealer to furnish a supply uniform in quality and in quantity, also the ability of the fuel to stand shipment. Sub-bituminous coals and lignite suffer much deterioration in handling. If a large supply must be kept on hand, the tendency to spontaneous combustion must be ascertained. Sub-bituminous coals and lignite, and bituminous coals in a finely divided state, are subject to such spontaneous combustion.

The following characteristics of the equipment should be considered:

A furnace with a small volume of combustion space or short flame travel is not adapted to burning high volatile coals at high rates of combustion.

Furnaces having a tile roof or Dutch oven are usually well adapted to burning high volatile coals, because of the larger combustion space and the maintenance of the heated brick work at the high temperature required for ignition. Arches, brick piers and wing-walls, which effect a more thorough mixture of air and combustible gases, will permit the use of higher volatile coals. In hand-fired furnaces the arch or tile roof should not be over the grate but above or beyond the bridge-wall. This position of the arch reduces the rate of heating of the freshly-fired coal and spreads the distillation over a longer period.

Plain grate bars are used with larger sizes of coal and with coals that produce considerable clinker, while herringbone or pin-hole grates are used with finer sizes. Shaking and dumping grates require less labor, and can therefore be used with high ash coals.

In stoker installations, it must be borne in mind that no type of stoker burns all sizes of coal with equal facility. For instance, highly caking, low-ash coals are not suited to the chain grate. This is best adapted to the free-burning, high-ash coals of the Middle West.

Where the draft is low, the larger sizes of coal of the free-burning type should be used. Coals that require a high draft are lignite, sub-bituminous and fine sizes of anthracite.

Draft requirements are affected by size, caking quality, ash content and clinkering qualities of coal.

Where manual labor is used, the handling of the coal and refuse is an item to be considered.

If the plant has a steady load and a high rate of combustion or a fluctuating load with heavy peaks, there will be difficulty in burning coals whose ash fusing temperatures are low. With a high rate of combustion the furnace temperature is usually high.

Much of the credit for success or failure of a coal is dependent upon the skill of the operating force.

Where the plant is located in a city having a smoke ordinance, the fuel must be so selected that the ordinance will not be violated. Cinder production may also be a detriment. One of the greatest aids in comparing fuels is a service test.

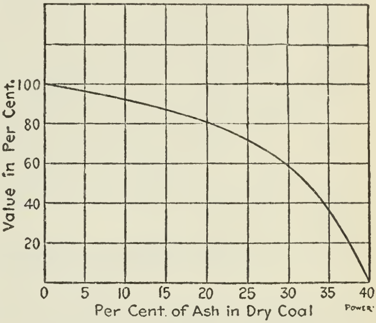
Effect of Ash on Coal Value.—Next to calorific value ash content is the most important factor in the commercial valuation of coal. The efficiency of combustion ordinarily decreases with increase of ash. There is also the additional expense for ash disposal.

The curve below, due to *A. Bement*, is intended to show the relative value of coals, depending upon the percentage of ash content.

Commercial coals contain 3% to 25% of ash. Coals with the smallest ash percentages have the greatest value, not only because of their higher heating values, but because they offer less resistance to the passage of air and to its distribution through the fuel bed. The labor and cost of managing the fire and the handling of the ashes must be considered. The greater the ash content, the lower the efficiency and the capacity.

High ash coals require higher draft, which results in more leakage of air through the furnace walls. The greater draft is required because the ash may form an insulating layer around the coal, so that the oxygen cannot come in contact with it. The ash may also clinker and clog the fuel bed. The following are the maximum limits of ash usually permitted in anthracite:

Furnace	10%	of	"dry coal."
Egg	11	"	" "
Stove	12	"	" "
Chestnut	14	"	" "
Pea	16	"	" "
Buckwheat No 1.	18	"	" "



VALUE OF COAL AS AFFECTED BY ASH CONTENT

Effect of Size of Coal.—The size of the coal influences the capacity of the boiler, owing to its effect on draft. With poor draft, fine coal cannot be burned in sufficient quantities to maintain the rated capacity. If thin fires are resorted to, the efficiency is usually lowered by holes in the fire. Dust and very fine coal check the air flow or pass up the stack unburned. Coal of uniform size is most satisfactory, as it does not pack so badly as other coal.

Effect of Moisture on Steam Value of Coal.—Moisture in coal reduces the efficiency of steam generating apparatus by

(*a*) Increasing the heat carried away by water vapor. 1% moisture means a loss of 13 BTU per pound of coal in superheated vapor in the stack gases when they have a temperature of 600° F.

(*b*) The escape of a larger quantity of free hydrogen.

Moisture also decreases the capacity, due to a lower rate of combustion, caused probably by dilution of the oxygen by a large quantity of water vapor.

Moisture reduces efficiency more than the same percentage of ash.

The "dry coal" analyses are convenient for comparing different coals.

The chart on page 44, adapted from *M. Gensch*, shows the effect of moisture on the value of a coal. It has been figured for average Illinois coal, and is fairly representative of the usual coals which contain moisture in sufficient amounts to have appreciable effects on economy. Since the price is at the mine or on delivery, excess above the minimum moisture at the mine is a pure loss to the purchaser. While moisture in coal is in general detrimental, due to the heat absorbed in evaporating and superheating it to the temperature of the flue gases, with some bituminous coals the moisture content produces a mechanical action that assists in combustion.

Effect of Oxygen on the Value of Coal.—Oxygen in coal is a diluent or "dead weight." It renders ineffectivo an equal combining weight of carbon, hydrogen or sulphur. Whereas DuLong's formula combines the oxygen only

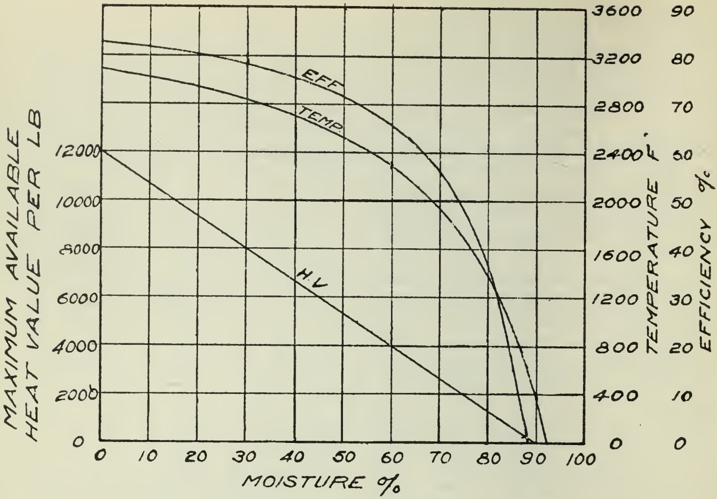


CHART INDICATING THE EFFECT OF MOISTURE ON THE VALUE OF COAL

Based on 12,000 BTU coal, containing no moisture. The maximum possible available heat is that obtainable above 600° F. flue gas temperature. The temperature of combustion and the maximum possible efficiency are based on 50% excess air (16.5 lbs. per lb. of dry coal) and a flue gas temperature of 600° F.

with hydrogen, in highly oxygenated coals nearly two-thirds of the oxygen appears in the volatile in union with carbon.

A comparison of numerous boiler tests by the *Bureau of Mines* shows that the boiler efficiency drops as the oxygen content increases. There is no logical course of reasoning to demonstrate that the oxygen should in any way cause a large increase of air or incomplete combustion. The decrease in efficiency is probably due to other causes, as high oxygen content is associated with moisture or ash or both.

The Effect of Sulphur on the Value of Coal.—The sulphur in a coal and the heating value are largely affected by the ash. If unnecessary ash is kept out at the mine, sulphur will be low, and the BTU value high. *Marks* states that while the sulphur content of coal is generally considered to produce clinkering, spontaneous combustion and corrosion, its connection with the first two is not definitely substantiated by experience. It is also certain that sulphur fumes do not attack metals under conditions of boiler operation, although they probably do attack economizer tubes filled with cold water.

Effect of Volatile on Coal Value.—The volatile content of coal is of indirect interest in indicating its general nature, but does not give any definite information about the burning qualities. The volatile in most coals includes some inert matter. The proportion varies in different coals, and therefore the heating value cannot be determined from the proximate analysis alone. Different coals with the same amount of volatile behave differently.

The steaming value of coals is very nearly proportional to the B.t.u. contents. In a large number of tests by the *Bureau of Mines* on coals ranging in heat contents from 14,600 to 10,200 B.t.u., the corresponding average efficiencies varied from 66 to about 62%.

THE PURCHASE OF COAL UNDER SPECIFICATIONS

An important means of increasing power plant economy is the use of better methods in the purchase of fuel.

J. A. Moyer points out that specifications secure a more uniform grade of coal, which permits a more careful study of the operation of a boiler plant. Operating conditions can be arranged to secure the best possible efficiency with the grade of coal supplied. Many operators believe this advantage is in itself worth the expense, which is considerable, of sampling and analyzing.

There are disadvantages in purchasing coal under specifications, most of which will eventually be overcome. The cost of the analyzing apparatus is considerable, and the services of a somewhat skilled man are required. Mine operators object to unreasonable specifications, and it is claimed that 90% of specifications offered are impossible in practical operation. The mine operator frequently adds 10% to his price for unexpected contingencies.

The *Bureau of Mines* mentions the following advantages:

1. The bidders are put on a strictly competitive basis.
2. The field is broadened for both bidder and purchaser.
3. The contract specifies an established standard of quality as a basis for adjusting the price.
4. If other coal must be substituted, there is a standard for settlement.
5. If coal is uniformly poorer than the standard set, there is a basis for cancellation.
6. When there is need of preparation at the mine (picking, washing, etc.), the operator, who is largely responsible for variations in the grade of such coal, is stimulated to prepare it better.

The useful items in a modern specification for coal purchase are the heat value and the water and ash contents.

In plants where boiler capacity and grate area are small, and the draft is weak, only the best grades of coal can be burned. It is therefore desirable to take bids on such plants on a general specification, so that bids can be received on coals of different quality. With the information obtained, the probable saving which would result from making radical changes in the plant, in order to take advantage of coals offered at lower costs per million BTU, can be determined.

Specifying the district from which the coal is to come is no guarantee. Every district can supply coal varying easily 10% in heating value.

The Government accepts as anthracite coals those mined in Susquehanna, Lackawanna, Luzerne, Carbon, Schuylkill, Columbia, Sullivan, Northumberland and Dauphin Counties, Pa. It accepts as bituminous all those usually classed as bituminous, together with sub-bituminous and semi-bituminous. Specification limits are wide enough to permit the use of the output from a group of mines.

Government specifications describe clearly the quality of coal desired, with the intention of enabling the bidder to furnish a definite statement of the quality of coal offered, this statement to be used as a standard or as a basis of payment in connection with the price stated. The bidder is not required to submit a sample, but must state the percentage of ash and the BTU in the coal as delivered.

The bidder is required to furnish the commercial name of the coal he proposes to deliver, and the name or local designation of the coal bed or beds.

It is not expected that all deliveries will be absolutely uniform or agree exactly with the standard, but it is necessary that all deliveries shall come within the limits set.

It is important not to neglect the matter of the allowed percentage of fine coal or slack. Nut and slack contracts generally read that the coal that can be sifted or screened through a screen having ¼-inch perforations shall not exceed 30%.

Moisture.—Prior to 1912 and 1913, Government specifications were written on a BTU-as-received basis. Payment was directly affected by the moisture content of the sample received by the laboratory. The moisture reported by the laboratory may be 5% to 10% lower than that actually contained at the time of weighing. This means that payment on this basis would be higher than warranted. The *Bureau of Mines* recommends that specifications be on a "dry coal" basis.

In preparing specifications, the fact is recognized that the moisture in a coal produced from day to day in the same mine will vary considerably, and is a matter over which either the buyer or the seller can exercise but little control. To place a negative value on high moisture coal and to protect the Government against coals of excessive moisture requires a statement of the maximum moisture content in the coal offered. This value becomes a standard for the contract.

If coal of uniform BTU on a dry coal basis is delivered, the contractor receives an advantage on a delivery on which the moisture content approaches the maximum specified, whereas if the coal is very dry the purchaser receives the advantage. It is equitable that the seller and the purchaser shall share the uncertainty.

The moisture determination in coal delivered from a stock pile is of great importance, as it may be 10% to 15% higher than when stocked.

Neither the "as received" nor the "dry" basis has proved altogether satisfactory. A satisfactory way of handling the moisture question has yet to be evolved.

Ash.—A great deal of anthracite has been purchased by the Government on an ash standard basis only. The comparison of tests shows that the per cent. ash in "dry coal" is a good index of the heating value.

Few specifications in use make any mention of the clinkering qualities of coal, although it is of great importance, and should be covered in all specifications. The fusing temperature is a measure of the clinkering, but its method of determination should be further investigated.

Anthracite for all purposes may, according to standard specifications, carry a certain percentage of rock, slate, or bone, according to the size of coal. A piece of coal containing hardly any carbon is classed as rock. A piece containing less than 40% carbon is classed as slate. A piece containing from 40% to 65% carbon is classed as bone. A piece containing over 65% of carbon is classed as coal. Egg coal may contain 2% of slate or rock, and 2% of bone. It must be free from mud or discoloration. Stove coal may contain 4% of slate or rock, and 3% of bone. It must be free from mud and discoloration. Chestnut or nut coal may contain 5% of slate or rock, and 5% of bone. It must be free from mud or discoloration. Pea coal may contain 10% of slate or rock, and not much more bone than slate. Its color must be fairly bright. No. 1 Buckwheat may contain 15% of slate or rock, and not so much bone as to make the mass look dull in color. Rice coal may contain up to 20% of slate. Barley coal must retain a fairly bright appearance.

Sulphur.—The *Bureau of Mines*, in its recommendation for specifications, does not exact a penalty for sulphur content, but does require that the contractor specify the sulphur content so that standards for coals to be delivered may be established. Many commercial and municipal specifications exact penalties for a slight increase. One deducts 5% in price for each 1% of sulphur in excess above the standard.

Volatile.—Both sulphur and volatile contents should be used to classify coals and to identify the coal guaranteed. Variations indicating substitutions of unsatisfactory coal should be considered a cause for rejection of the coal, or for cancellation.

In the *Bureau of Mines* specifications, the contractor is required to give the volatile content and the complete proximate analysis. This becomes a standard for the contract, and delivery of coal with different percentages of volatile, indicating substitution, may result in the coal being rejected and the Government purchasing coal in the open market, the contractor being charged with the difference in price, or in cancellation of the contract.

The Government does not consider a penalty for volatile variations equitable, because the per cent. of volatile does not indicate the character of it nor the heating value of the coal. Some commercial and municipal specifications apparently disregard this fact, and state penalties for volatile variations. This offers ground for opposition from coal companies.

Where smoke laws are to be observed, it may be necessary to specify also a maximum volatile content for the coal. However, it would generally be advisable and economical to alter the furnace and boiler conditions to burn a cheaper high-volatile fuel.

Method of Sampling.—The method of sampling should be included in the specifications. Probably more difficulties arise on account of the improper sampling than for any other reason. Mechanical means of sampling are considered the best. Alternate methods of analysis are not desirable, and standard specifications should always specify one standard practice.

Service Tests.—Specifications recommended by the *Bureau of Mines* provide that before a final award of contract, practical service tests may be made to determine the relative suitability of the coals offered.

Bonuses and Penalties.—The *Bureau of Mines* suggests the following: For adjusting the price on the BTU variation, use the following:

$$\frac{\text{BTUs delivered}}{\text{BTUs standard}} \times \text{contract price} = \text{price to be paid.}$$

The price should be further corrected for variations in ash, in the dry coal; for all coal which by analysis contains less ash than that established in the contract, a premium of 1 cent per ton for each whole per cent. less ash would be paid, and an increase in the ash content of 2% over the standard established by the contractor would be tolerated without exacting a penalty for excess ash, but when such excess exceeded 2% above the standard established, deductions would be made from the price paid per ton in accordance with the table under sample Government specifications.

Comparison of Bids.—After all bids have been received, they should be reduced to a common basis for comparison. The preferable method is to adjust them to the same ash percentage by selecting as a standard that proposal which offers the coal containing the lowest percentage of ash. Each one per cent. of ash content above that of this standard is assumed to have a negative value of two cents per ton, the amount of the penalty which is exacted under the contract requirements for 1% excess of ash. The proposal prices are adjusted in this manner, and so tabulated. On the basis of this adjusted price, allowance is made for the varying heat values by computing the cost of 1,000,000 BTU for each coal offered. Thus the three variables are all merged in a single figure for comparison, including heat value, percentage of ash, and price per ton.

OUTLINE SPECIFICATION OF COAL

By *Morgan B. Smith*

- PARTIES TO CONTRACT
  - Seller
  - Purchaser
    - General and Specific Clauses
      - Producer's or seller's bond—Surety Co.
      - Coal to be furnished
        - Trade name
        - Region mined—state mines, seams
        - Size limits, if any
        - Quantity (Max.)
          - % allowed for varying requirements—pro rata tonnage in case of strikes
          - Reserve for test purposes—right to buy on open market—% of max. quantity
      - Purchaser's Option
        - Rights in case of seller's failure to fulfill contract—annulment of contract clause
      - Shipments
        - Notice to seller as to requirements
        - Delivery
          - When—period
          - Where—tracks at yards
          - How—types of cars desired
          - Routing
          - Weights
            - Railway bills expense to purchaser
            - Purchaser's weights
      - Payments
        - Price
          - Mines—
          - Freight—changes in rates—how adjusted
            - When to be made—monthly or otherwise
        - Basis-quality
          - Specification—Bonus & penalty clause—Scale of price per ton
            - Sizing
            - B. T. U. dry coal
            - % ash & fusing point
            - Volatile
            - Fixed carbon
            - Sulphur
            - Nitrogen
              - Inspection clause
          - Tests for Quality
            - Made by whom — Test to be made named
              - When
              - Where
                - by whom—seller—purchaser—referee
              - Methods to be followed
                - Sampling
                - Analysis
            - Test Reports
              - Forms
              - Sent to whom

Bidder	Heat Value "as Received"	Ash in "Dry Coal"	Price per Ton Bid	Price per Ton Plus Ash Dif.	Cost per 1,000,000 BTU, in cents
A	13400	10	$2.35	$2.43	8.096
B	14000	8	3.15	3.19	10.172
C	14600	6	3.25	3.25	9.938
D	13000	10	3.10	3.18	10.920
E	13000	8	2.35	2.39	8.207
F	13000	10.5	2.35	2.44	8.379
G	11500	13.5	2.25	2.40	9.317

Typical Specifications.—The outline on the opposite page indicates the points to be considered in drawing up specifications. The sample specifications quoted in full in the following pages were prepared by the *Bureau of Mines* for the use of Government Departments.

SPECIFICATIONS AND PROPOSALS FOR BITUMINOUS AND ANTHRACITE COAL

I. Proposals

1. **Date to be Delivered.**—Sealed proposals, in duplicate, on blank forms supplied by the...................., to furnish such quantities of coal as specified herein as may be required for use of the.................., for the fiscal year ending June 30, 191.., will be received until 2 o'clock p. m., ..., at the office of the...................., and then opened.

2. **Bidder May be Present.**—Each bidder shall have the right to be present, either in person or by attorney, when the bids are opened.

3. **Address of Proposals.**—Proposals, in duplicate, must be forwarded to the............................, postage prepaid. Addressed envelope for mailing is inclosed herewith.

4. **Form and Signature.**—Proposals must be made in duplicate on the form given herein, and must be signed by the individual, partnership, or corporation making the same; when made by a partnership, the name of each partner must be signed. If made by a corporation, proposals must be signed by the officer thereof authorized to bind it by contract, and be accompanied by a copy, under seal, of his authority to sign.

5. **Cash or Certified Check.**—The proposals must be accompanied by cash or by certified check drawn payable to the order of the................, in the amount equal to 2 per cent. of the estimated amount involved for the fuel for which bids are submitted, the minimum amount in any case to be $10. This requirement is solely to guarantee, if the award is made on the proposal, that within 10 days after notice is given that an award has been made, the bidder will enter into a contract in accordance with the terms of the proposal and execute a bond for the faithful performance thereof, with good and sufficient sureties as hereinafter required. In the event of the failure of the bidder to enter into contract or execute bond, the cash or check guaranty will be forfeited.

II. Contractor's Bond

6. **Sureties.**—Each contractor shall be required to give a bond, with two or more individual sureties or one corporate surety duly qualified under the act of Congress approved August 13, 1894, in which the contractor and the sureties shall covenant and agree that, in case the said contractor shall fail to do or perform any or all of the covenants, stipulations, and agreements of said contract on the part of the said contractor to be performed as therein set forth, the said contractor and his sureties shall forfeit and pay to the

United States of America any and all damages sustained by the United States by reason of any failure of the contractor fully and faithfully to keep and perform the terms and conditions of his contract, to be recovered in an action at law in the name of the United States in any proper court of competent jurisdiction. Such sureties (except corporate sureties) shall justify their responsibility by affidavit showing that they severally own and possess property of the clear value in the aggregate of double the amount of the abovementioned forfeiture over and above all debts and liabilities and all property by law exempt from execution; the affidavit shall be sworn to before a judge or a clerk of a court of record or a United States attorney, who must certify of his own personal knowledge that the sureties are sufficient to pay the full penalty of the bond.

7. **May be Waived.**—If the estimated amount involved in the contract does not exceed the sum of $200, then the bond may be waived with the consent of the department involved.

III. Reservations

8. **Rejection of Bids.**—The right is reserved by the Government to reject any and all bids and to waive technical defects. Bidders are cautioned against guaranteeing higher standards of quality than can be maintained in delivered coal (this applies especially to bituminous coal and the steam sizes of anthracite), as the Government reserves the right to reject any and all bids, if the Government has information regarding analyses and test results that indicate that higher standards have been offered than probably can be maintained.

9. **Tests.**—The right shall be reserved by the Government to purchase for the purpose of making boiler tests other coal than that herein contracted for, provided the amount so purchased shall not exceed 10 per cent. of the estimated consumption during the period covered by this agreement.

10. **Lowest Bids May Not be Considered.**—If it should appear to be to the best interests of the Government to do so, the right is reserved to award the contract for supplying coal at a price higher than that named in a lower bid, or in lower bids.

11. **Failure to Contract.**—If the bidder to whom the award is made shall fail to enter into a contract as herein provided, then the award may be annulled and the contract let to the next most desirable bidder without further advertisement, and such bidder shall be required to fulfill every stipulation expressed herein, as if he were the original party to whom the contract was awarded; provided, however, that such bidder is notified of said award within 60 days after the date on which the bids on this contract were opened. If such notice should not be given within said 60 days, then the acceptance of the award will be optional with the said bidder.

12. **Contracts Non-Transferable.**—No contract can be lawfully transferred or assigned.

13. **Default.**—No proposal will be considered from any person, firm, or corporation in default of the performance of any contract or agreement made with the United States, or conclusively shown to have failed to perform satisfactorily such contract or agreement.

IV. Quantity

14. The estimated quantity of coal in.................... tons of 2,000 pounds to be purchased is based upon the previous annual consumption, but the right will be reserved to order a greater or less quantity, subject to the actual requirements of the service.

V. Delivery

15. **Quantity, Time and Place.**—The coal shall be delivered in such quantities at such times as the Government may direct. (Place of delivery to be stated.)

16. **Rapidity.**—All the available storage capacity of the Government coal bunkers shall be placed at the disposal of the contractor to facilitate delivery of coal under favorable conditions. When an order is issued for coal, the contractor upon commencing a delivery on that order shall continue the delivery with such rapidity as not to waste unduly the services of the Government inspector.

17. **Failure to Deliver.**—After verbal or written notice shall have been given to deliver coal under this contract a second notice may be served in writing upon the contractor to make delivery of the coal so ordered within a reasonable time, to be determined by the Government official in charge, after receipt of said second notice. Should the contractor for any reason fail to comply with the second request, the Government shall be at liberty to buy coal independently of this contract, and for coal so purchased to charge against the contractor and his sureties any excess in price over the price which would have been paid to the contractor had the coal been delivered by him.

18. **Hours.**—The contractor shall be allowed to deliver coal during the usual hours of teaming—that is, between 8 a. m. and 5 p. m.

19. **Weighing.**—(To be stated by whom and where the coal shall be weighed, etc.)

VI. Sampling

20. **Contractor Privileged to be Present.**—The contractor shall have the privilege of having a representative present to witness the collection and preparation of the samples to be forwarded to the laboratory.

21. **Method.**—The samples shall be collected and prepared in accordance with the method given in Appendix A. (See pages 18 and 19.)

VII. Analyses

22. **Laboratory and Method.**—The samples shall be immediately forwarded to the *Bureau of Mines*, Department of the Interior, Washington, D. C., and they shall be analyzed and tested in accordance with the method recommended by the American Chemical Society and by the use of a bomb calorimeter. Such analyses and tests shall be made at no cost to the contractor. The results shall be reported by the *Bureau of Mines* in not more than fifteen (15) days after the receipt of the sample. If more than one sample is received from the same delivery, the fifteen (15) days shall date from the receipt of the last sample taken.

VIII. Bituminous and Anthracite Pea and Buckwheat Coal for Power and Heating Plants

DESCRIPTION OF COAL DESIRED

23. **Kind and Quality.**—The coal must be a good coal............... (kind and size to be specified), and must be adapted for successful use in the particular furnace and boiler equipment.

24. **Information to be Supplied by Bidder.**—Bidders are required to specify the coal offered in terms of moisture in the coal "as received," and of ash, volatile matter, sulphur, and British thermal units in "dry coal," such values to become the standards for the coal of the successful bidder. In addition, the bidders are required to give the trade name of the coal offered, the name or other designation of coal bed, name of mine or mines, location of mine or mines (town, county, and State), railroad on which mine or mines

are located, and name of operator of mine or mines. This information shall be furnished in spaces provided hereinafter.

NOTE.—Bids not supplying the foregoing information may be considered informal and rejected.

Coal of the description and analysis specified is herein known as coal of the contract grade. Bidders are cautioned against specifying higher standards than can be maintained, for to do so will result in deductions in price and may result in the rejection of delivered coal or the cancellation of the contract. In this connection it should be recognized that the small "mine samples" usually indicate a coal of higher economic value than that actually delivered in carload lots, because of the care taken to separate extraneous matter from the coal in the "mine samples."

AWARD

25. **Considerations.**—In determining the award of this contract consideration will be given to the quality of the coal (expressed in terms of moisture in coal "as received," of ash in "dry coal," and British thermal units in "dry coal") offered by the respective bidders and to the operating results obtained with the same and with similar coals on previous contracts or by test, as well as to the price per ton.

26. **Bids Subject to Rejection.**—Bids may be rejected from further consideration if they offer coals regarding which the Government has information that they possess unsatisfactory physical characteristics or volatile matter or sulphur or ash contents, or that they are unsatisfactory because of clinkering or excessive refuse, or because of having failed to meet the requirements of city smoke ordinances, or for other cause that would indicate that they are of a character or quality that the Government considers unsuited for the storage space or the furnace equipment of the particular contract.

27. **Method of Comparing Bids.**—In order to compare bids as to the quality of the coal offered, all proposals shall be adjusted to a common basis. The method used shall be to merge the four variables—moisture content, ash content, heating value, and price bid per ton—into one figure, the cost of 1,000,000 British thermal units. The procedure under this method shall be as follows:

(*a*) All bids shall be reduced to a common basis with respect to moisture, by dividing the price quoted in each bid by the difference between 100 per cent. and the percentage of moisture guaranteed in the bid. The adjusted bids shall be figured to the nearest tenth of a cent.

(*b*) The bids shall be adjusted to the same ash percentage by selecting as the standard the proposal that offers coal containing the lowest percentage of ash. The difference in ash content between any given bid and this standard shall be divided by 2 and the price in such bid, adjusted in accordance with the above, multiplied by the quotient. The result shall be added to the above adjusted price. The adjusted bids shall be figured to the nearest tenth of a cent.

(*c*) On the basis of the adjusted price, allowance shall then be made for the varying heat values by computing the cost of 1,000,000 British thermal units for each coal offered. This determination shall be made by multiplying the price per ton adjusted for ash and moisture contents by 1,000,000, and dividing the result by the product of 2,000 multiplied by the number of British thermal units guaranteed. If the coal is purchased on the basis of 2,240 pounds to the ton, the factor of 2,240 should be used instead of 2,000.

28. **Service Test.**—After the elimination of undesirable bids, the selection of the lowest bid of those remaining on the basis of the cost per 1,000,000 British thermal units may be considered by the Government as a tentative

award only, the Government reserving the right to have practical service test or tests made under the direction of the *Bureau of Mines*, the results to determine the final award of contract. The interested bidder or his authorized representative may be present at such test.

CAUSES FOR REJECTION

29. **Coal Subject to Rejection.**—It is understood that coal containing 3 per cent. more moisture, or 4 per cent. more ash, or 3 per cent. more volatile matter, or 1 per cent. more sulphur, or 4 per cent. fewer British thermal units than the specified guaranties as to the standards for the coal hereunder contracted for, or coal furnished from a mine or from mines other than herein specified by the contractor, unless upon written permission of the Government, shall be considered subject to rejection, and the Government may, at its option, either accept or reject the same. Should the Government have consumed a part of such coal subject to rejection, such consumption shall not impair the Government's right to cause the contractor to remove the remainder of the delivered coal subject to rejection.

30. **Cancellation of Contract—Open Market Purchases.**—It is agreed that if the contractor shall furnish coal in three consecutive deliveries, or in case more than 20 per cent. of the coal delivered to any date during the life of this contract shall contain 3 per cent. more moisture, or 2 per cent. more ash, or 3 per cent. more volatile matter, or 1 per cent. more sulphur, or 2 per cent. fewer British thermal units than the specified guaranties as to the standards for the coal hereunder contracted for, or if coal is furnished from a mine or from mines other than herein specified, unless upon the written permission of the Government, then this contract may, at the option of the Government, be terminated, or the Government may, at its option, purchase coal in the open market until it may become satisfied that the contractor can furnish coal equal to the standards guaranteed, and the Government shall have the right to charge against the contractor any excess in price of coal so purchased over the corrected price that would have been paid to the contractor had the coal been delivered by him.

31. **Removal of Rejected Coal.**—The contractor shall be required to remove, without cost to the Government, within 48 hours after notification, coal that has been rejected by the Government. Should the contractor not remove rejected coal within the said 48 hours, the Government shall then be at liberty to have the said coal removed from its premises and to dispose of such coal by sale, as the Government shall elect. The proceeds from such sale, less all costs incidental to its removal and to the sale, shall be paid over to the contractor.

PRICE AND PAYMENT

32. **Determination of Price.**—The Government hereby agrees to pay the contractor within thirty (30) days after the completion of an order or delivery for each ton of 2,000 pounds of coal delivered and accepted in accordance with all the terms of this contract, the price per ton determined by taking the analysis of the sample, or the average of the analyses of the samples if more than one sample is analyzed, collected from the coal delivered upon the basis of the price herein named, adjusted as follows for variations in heating value, ash content, and moisture content from the standards guaranteed herein by the contractor. (See paragraph 13 in appendix (page 20) for exception to this method):

(*a*) **Heat Unit Adjustment.**—Considering the coal on a "dry-coal" basis, no adjustment in price shall be made for variations of 2 per cent. or less in the number of British thermal units from the guaranteed standard.

When the variation in heat units exceeds 2 per cent. of the guaranteed standard, the adjustment shall be proportional and shall be determined by the following formula:

$\frac{\text{B. t. u. delivered coal ("dry-coal" basis)}}{\text{B. t. u. ("dry-coal" basis) specified in contract}} \times \text{bid price} = \text{price resulting}$ for B. t. u. variation from the standard.

The adjusted price shall be figured to the nearest tenth of a cent.

As an example, for coal delivered on a contract guaranteeing 14,000 British thermal units on a "dry-coal" basis at a bid price of $3 per ton, showing by calorific test results varying between 13,720 and 14,280 British thermal units, there would be no price adjustment. If, however, by way of further example the delivered coal shows by calorific test 14,350 British thermal units on a "dry-coal" basis, the price for this variation from the contract guaranty would be, by substitution in the formula: $\frac{14{,}350}{14{,}000} \times \$3 = \$3.075$

(*b*) **Ash Adjustment.**—No adjustment in price shall be made for variations of 2 per cent. or less below or above the guaranteed percentage of ash on the "dry-coal" basis. When the variation exceeds 2 per cent., the adjustment in price shall be determined as follows:

The difference between the ash content by analysis and the ash content guaranteed shall be divided by 2 and the quotient shall be multiplied by the bid price, and the result shall be added to or deducted from the B. t. u. adjusted price or the bid price, if there is no B. t. u. adjustment, according to whether the ash content by analysis is below or above the percentage guaranteed. The adjustment for ash content shall be figured to the nearest tenth of a cent.

As an example of the method of determining the adjustment in cents per ton for coal containing an ash content varying by more than 2 per cent. from the standard, consider that coal for which the above-mentioned heat unit adjustment is to be made has been delivered on a contract guaranteeing 10 per cent. ash, and shows by analysis an ash content of 7.50 per cent. The adjustment in price would be determined as follows:

The difference between 10 and 7.50, which is 2.50, would be divided by 2, and the quotient of 1.25 multiplied by $3, resulting in an adjustment of 3.7 cents per ton, which in this case would be an addition. The price after adjustment for the variations in heating value and ash content would be $3.075 plus $0.037, or $3.112.

(*c*) **Moisture Adjustment.**—The price shall be further adjusted for moisture content in excess of the amount guaranteed by the contractor, the deduction being determined by multiplying the price bid by the percentage of moisture in excess of the amount guaranteed. The deduction shall be figured to the nearest tenth of a cent.

As an example, consider that coal for which the above-mentioned heat unit and ash adjustments are to be made, and as having been delivered on a contract guaranteeing 3 per cent. moisture, and that the coal shows by analysis 4.50 per cent. moisture; then the bid price would be multiplied by 1.50 (representing excess moisture), giving 4.5 cents as the deduction per ton. The price to be paid per ton for the coal would then be $3.112, less $0.045, or $3.067.

33. **Partial Payment.**—If coal on visual inspection by the Government inspector appears to be acceptable coal, the Government shall have the right, immediately on the completion of an order, to make payment on 90 per cent. of the amount of the bill, based on the tonnage delivered and the bid price

per ton. The 10 per cent. withheld is to cover any deduction on account of the delivery of coal that on analysis and test is subject to an adjustment in price. If the 10 per cent. withheld should not be sufficient to cover the deduction, then the amount due the Government may be taken from any money thereafter to become due to the contractor, or may be collected from the sureties. Because of the distance of the point of delivery from the laboratory, requiring several days for the transmittal of samples and the return of analytical report, because of loss of the original sample, necessitating the forwarding of the reserve sample, or for any other reason that would result in delayed payment, should such be withheld until receipt of analytical report, the Government may, as circumstances in its opinion warrant, exercise the foregoing right.

IX. Anthracite Coal—Domestic Sizes

DESCRIPTION OF COAL DESIRED

34. **Character and Quality.**—The coal must be best quality, fresh-mined, anthracite, and it must be well screened, practically free from dirt, must not contain undue percentages of moisture, slate, or bone, or of coal of smaller sizes, and must equal in quantity and preparation the best anthracite coal produced.

35. **Information to be Supplied by Bidder.**—The bidder shall be required to give the trade name of the coal offered, the name or other designation of coal bed or beds, the name of mine or mines producing the coal, location of mine or mines (town, county, and State), the name and address of the operator of mine or mines, and the railroad upon which the mine or mines are located, this information to be given in spaces provided hereinafter.

AWARD

36. **Considerations.**—In determining the award of the contract, consideration shall be given to the results obtained with coals furnished on previous Government contracts by the respective bidders, as well as to the price per ton.

CAUSES FOR REJECTION

37. **Unsatisfactory Coal.**—If the percentage of bone, dirt, slate, or smaller sizes in a delivery exceeds the percentage required by the best preparation, or if the given coal fails to give satisfactory results because of excessive clinkering or excessive ash-pit refuse, it shall be subject to rejection, and payment may not be made for the remaining coal, and the Government shall have the right to cause the contractor to remove such coal at no cost to the Government. The Government may then purchase coal in the open market and make charge against the contractor for the excess in cost of coal so purchased.

38. **Ash Deduction.**—If it is impracticable for the Government to cause the contractor to remove coal that produces excessive ash-pit refuse, samples may be taken during the consumption of such coal, provided not more than 50 per cent. of the delivery had been consumed, and if on analysis the ash content on the "dry-coal" basis is equal to or greater than the following percentages for the respective sizes of coal, ten (10) per cent. of the price of the delivery in question shall be deducted from any money due or that may thereafter be due the contractor:

Size of Coal	Ash in "Dry Coal," Per Cent.
Furnace	14
Egg	15
Stove	16
Chestnut	18

39. **Unacceptable Coal.**—The Government inspector will not accept coal if, in his opinion, on visual inspection, it is subject to rejection, or if it

contains an undue percentage of moisture, and he shall have the right to refuse to accept coal from a source other than that specified by the bidder, unless the contractor shall have received permission from the Government to substitute said coal.

40. **Cancellation of Contract.**—If the contractor furnishes coal in three consecutive deliveries, or in case 20 per cent. of the amount of the coal delivered to any date during the life of the contract is, in the opinion of the Government, subject to rejection, then the contract may, at the option of the Government, be terminated by written notice to the contractor to that effect.

PRICE AND PAYMENT

41. Payment shall be made within thirty (30) days after the completion of an order and shall be based on the contract price, provided the coal is not subject to rejection.

X. Information to be Supplied by Bidders

42. The following spaces should be filled in by the bidder for each bid, for if the information called for is not supplied, the proposal may be regarded as informal.

(Bidders are cautioned against specifying higher standards than can be maintained, for to do so may result in the bid being rejected, or may result in rejection of delivered coal or cancellation of the contract and the Government purchasing coal in the open market and charging against the contractor the difference in cost. See paragraphs 8, 29, 30, 31.)

....
(To be signed by office issuing proposals.)

The undersigned agree.. to furnish to the.......................... the coal described below, in tons of 2,000 pounds each, and in quantity as may be required during the fiscal year ending June 30, 191.., in accordance with the foregoing specifications; the coal to be delivered in such quantities and at such times as the Government may direct.

(*a*) Kind and size of coal..................................
(*b*) Commercial name of coal...............................
(*c*) Name of mine or mines..................................
(*d*) Location of mine or mines (town, county, and State)............
(*e*) Name or other designation of coal bed or beds..................
(*f*) Railroad on which mine or mines are located...................
(*g*) Name of operator of mine or mines........................
(*h*) Percentage of moisture in coal "as received"....................
(*i*) Percentage of ash in "dry coal"..........................
(*j*) Percentage of volatile matter in "dry coal"....................
(*k*) Percentage of sulphur in "dry coal"........................
(*l*) British thermal units per pound of "dry coal"..................
(*m*) Additional description of coal deemed of importance by the bidder..
....

(*n*) Price per ton of 2,000 pounds for delivery (for bituminous coal and for pea and buckwheat sizes of anthracite this price is understood to be the bid price per ton, see paragraph 32 for method of determining price for delivered coal)...

NOTE.—The information called for under *h*, *i*, *j*, *k*, and *l* is not required for bids on the domestic sizes of anthracite coal; that is, furnace, egg, stove, and chestnut.

The rules for sampling given on pages 15 to 20 are attached as an appendix to these specifications.

THE WASHING OF COAL

The *Bureau of Mines* ran evaporative tests and made analyses on 26 different coals, both raw and washed. The washed coals either burned more freely or seemed to burn more rapidly than the raw coal. The percentage of capacity developed was considerably greater with the washed than with the unwashed coal. The averages of the results of 26 tests are given below:

	Raw	Washed
Moisture in coal as fired	7.48	8.06
Ash as fired	12.48	7.84
Sulphur in coal as fired	2.99	2.24
Sulphur in dry coal	3.29	2.50
Ash in dry coal	13.54	8.58
Clinker in refuse	42	41
Volatile in combustible	40.50	40.82
Per cent. rated capacity	89.9	96.6
Efficiency	66.95	64.82
Black smoke, per cent	18.1	26.3
Carbon monoxide	.12	.19
Unaccounted for loss	9.41	12.40

In the washed coal a small amount of the sulphur had been removed, and a considerable amount of the ash. The washed coals gave a lower efficiency, and burned with a much greater amount of smoke.

In a suitably designed plant, washed coal offers a means of running at high capacity and good efficiency, but in the average hand-fired plant capacity is gained at the expense of efficiency.

STORAGE OF COAL AND CONSEQUENT WEATHERING

The storage of coal is made necessary because of market conditions, the danger of labor difficulties at the mines and on the railroads and shortage of transportation facilities.

Anthracite is the best coal for storing. It is not subject to spontaneous combustion, and can therefore be stored in unlimited amounts in one pile. Bituminous coal will ignite, and will suffer disintegration.

Two changes may take place in coal, first the oxidation of the inorganic matter, such as pyrites; there is a marked increase in volume, sometimes an increase in weight, and marked disintegration; second, the oxidation of the organic matter of the actual coal. This cannot be detected by the eye, but leads to the loss of heating value through the oxidation of hydrogen and carbon and the absorption of oxygen by the unsaturated hydrocarbon. According to *Steam*, the loss may run up to 10%, when stored in air, and 8¾% when stored under water.

A really important feature is the initial temperature of the coal at the time of storage. It should be handled during the coolest part of the day. The heat of a summer day, even in the temperate zone, makes it dangerous to store coal during the bright sunlight period. After the storage is once effected, it is not necessary that the sun's rays be deflected, since the heat absorbed during the day is liberated at night.

The *University of Illinois* ran extensive experiments on the weathering of coal. The most rapid loss occurred during the first week or ten days. It was slow thereafter, and continued indefinitely. The loss was greater in small coal, due to the proportionately greater exposed surface. The loss in covered bins was substantially the same as in open bins. "In coals tested, 1% is about the average loss for the first week, and 3% to 3½% will cover the loss for a year, although in some cases the loss was found to be as high as 5% in a year." *Hays* says these figures are in excess of what should be expected in commercially stored coal.

The *Bureau of Mines* found the loss in different bituminous coals due to differences of storing to be as follows:

New River coal: The loss in heating value in one year, stored in the open, was less than 1%. The loss in heating value in two years in the open was 1.85%. The loss in heating value in one year, submerged, practically nothing. There was no slacking of lumps in run-of-mine. Fresh and salt water were equally good for storing coal.

Pocahontas: The loss in calorific value in one year when stored in the open was 0.4%. There was little slacking.

Pittsburgh coals (gas coal): There was no measurable loss in calorific value in one year, even in the top six inches.

Wyoming coal: Loss in calorific value in three months 2.5%, 5.3% in 2¾ years. There was very bad slacking at the surface, but it only penetrated 12 or 18 inches.

The loss in one year by weathering Illinois coal was between 1% and 3%.

The storage of coal under water unquestionably preserves its heating value, but it necessitates the firing of wet coal. Illinois and Wyoming coals retain 5% to 15% moisture, even after draining. High-grade Eastern coals retain only 2% to 3%. This makes no difference where the fireman is allowed to wet down the coal anyway. The submerging of stored coal is an absolute preventative of spontaneous combustion, and on that score may be justified. Unless the storage period is more than a year, there is no reason for storing under water to conserve the heat value.

The losses due to spontaneous heating are more serious than deterioration at ordinary temperatures in the storage of coal. Spontaneous combustion is brought about by slow oxidation in an air supply sufficient to support oxidation, but insufficient to carry away all the heat formed.

The amount of surface exposed is one determining factor. Dust is therefore a dangerous form of coal for storage, particularly if mixed with lumps of such size that the interstices permit the flow of a moderate amount of air in the interior.

The volatile matter does not of itself increase the liability of coal to spontaneous heating. Two thousand letters were sent out by the *Bureau of Mines* to large coal consumers. In 1200 replies, 260 reported spontaneous combustion, 220 gave the name of the coals, which were classified as follows:

95 semi-bituminous, low volatile Appalachian coals.
70 higher volatile, Appalachian coals.
55 Western and Middle Western coals.

This shows that there was no reason for especial confidence in low volatile or smokeless coals for safety in storage.

High volatile Western coals usually are very liable to spontaneous heating, but they owe this property to their chemical nature. The oxygen content appears to bear a direct relation to the avidity with which coal absorbs oxygen. High oxygen coals absorb oxygen readily, and have a marked tendency to spontaneous combustion.

The effect of moisture on spontaneous combustion is a question on which opinions differ. *Richters* says that in the laboratory moist coal oxidizes more rapidly. In no instances of spontaneous combustion investigated by the *Bureau of Mines* could it be proved that moisture had been a factor.

Whereas there is no conclusive data as to the effect of the sulphur content upon storing coal, laboratory experiments by the *Bureau of Mines* showed that there was practically no reduction in the total sulphur in the coal when air at 120° C. was passed through it, although sufficient heat was developed to bring the coal almost to the ignition point. Indications are that sulphur content contributes very little to spontaneous heating.

A fire in the coal pile cannot be put out by drenching the pile. A crust forms over the fire, preventing the water from reaching it. The coal must be removed from around the burning part, and spread out. Water can then effectively be used on the burning part. In practice, coal stored two months, if re-handled and cooled, seldom again heats spontaneously.

The following precautions are suggested for coal storage, although some may prove impractical and expensive under certain conditions:

1. Do not pile over 12 feet, nor so that any point in the interior will be over 10 feet from an air-cooled surface.
2. If possible, store only screened nut coal.
3. Keep out the dust as much as possible; reduce the handling to a minimum.
4. Pile so that the lumps and the fine are distributed as evenly as possible, not allowing lumps to roll to the bottom, forming air passages.
5. Re-handle and screen after two months.
6. Do not store near external sources of heat, even though the heat transmitted be moderate.
7. Allow six weeks seasoning after mining and before storing.
8. Avoid alternate wetting and drying.
9. Avoid air transmission to the pile through interstices around foreign objects, brickwork, etc., or through porous bottoms, such as coarse cinders.
10. Do not ventilate with pipes, which may do more harm than good.

Analyses by the *Bureau of Mines* showed the following losses in heat value in coal in transit. The losses were due to the oxidation of the new surface of the coal after mining.

Semi-bituminous New River and Pocahontas	0.1%
Bituminous Appalachian	0.3%
Bituminous from Illinois, Indiana and Missouri	0.8%
Sub-bituminous and lignite	1.3%

COAL MEASUREMENT

Same measure of coal consumption is required for comparison with steam production in order to determine the evaporation per pound of coal and hence the efficiency. The method to be used for measuring coal in the boiler plant depends upon the method of handling. Coal is transported either continuously by belts, chutes or chain bucket conveyors, or intermittently by grab buckets, tipping buckets or hoppers carried on cranes. In a few plants coal is transported directly from cars or the holds of vessels to the stoker hoppers. More frequently one or two places of storage intervene in the form of stock piles or bins, the most common form being an overhead bunker in the boiler room. Coal is transported to the bunker by grab buckets operated by cranes or skip hoists, taking either from the coal car, vessel or pit into which coal cars are dumped, or by continuous belts or conveyors. With most kinds of coal and most types of stokers a crusher is interposed somewhere in this path. The weighing may be done in this part of the process, either by means of track scales weighing loaded coal cars, or by continuous weighing machines where belt or chain bucket conveyors are used. The transfer of coal from the overhead bunker or other intermediate storage to the stoker hopper is frequently by means of gravity chutes. These may be used to measure the coal by means of two valves or dampers, or a continuous coal measuring machine, such as a screw in the chute, may be interposed. In other cases coal is drawn from the overhead bunker into a bucket or larry mounted on a crane or carried by a monorail, which can be provided with scales. Volumetric coal measuring machines are also available for discharging coal in regulated amounts. Intermittently operated or continuous coal weighing machines can also be used to weigh the coal out into the larry. Where coal is transported by hand, the ordinary method of measuring it is to wheel it over platform scales.

OIL FUELS

Petroleum or crude oil is mineral oil composed of the paraffine, ethylene and naphthalene series of hydrocarbons. Fuel oil is either crude oil or the residue after the more volatile oils have been distilled.

Supply.—There is available for steam raising 2% or 3% of the products of the Pennsylvania and Ohio fields; an amount from Ohio, Indiana and Oklahoma depending on whether the price can compete with coal; most of the California oil; and practically all of the Texas oil.

Composition.—All mineral oils are nearly alike in ultimate composition, but there is an amazing difference in physical properties. Oils are absolutely ash-free when clean, all give vapors on heating, and have calorific values very close together, compared with the variations found in coals. Fuel oils are classified according to several characteristics, which are more or less dependent upon each other. Some of these are flash point, or the temperature at which oil gives off inflammable vapors; viscosity, which may be explained as molecular friction; specific gravity; heat value and sulphur content.

Flash point is of interest from the standpoint of safety. In land installations oil is usually kept in a closed storage tank and the danger is minimized.

Viscosity is the principal consideration in the burning of an oil, because the success of a burner depends largely on its ability to atomize the fuel sufficiently for complete combustion. A common method of comparing viscosity is on the Engler scale. Degs. Engler means simply the ratio of time for a given quantity of oil to flow through a standard orifice, as compared with the time for the same volume of water. The viscosity of many fuel oils is very high and they must be heated before they can be pumped.

Water is usually found mixed with crude oil. In the lighter oils it separates and settles. In the heavier grades it stays as an emulsion. In the first case, a slug of water may go to the burners, putting out the flame. In the second, the water is probably an advantage, as in the burner it vaporizes and assists in the atomization.

Oil is sold in 42-gallon barrels, weighing about 336 lbs. It is purchased on the basis of specific gravity (measured in degrees Baumé), heat value and moisture content.

$$\text{Deg. Bé. for liquids lighter than water} = \left(\frac{140}{\text{specific gravity}} - 130\right)$$

The specific gravity of crude oils lies between .80 and .97, (45° to 14° Bé.) the flash point being between 76° and 93° F., and the composition by weight is 84% to 88% carbon, and 11½% to 14½% hydrogen, with small percentage of impurities. The fuel oils (or reduced oils) have a specific gravity about .90, and a flash point between 240° and 270° F.

ANALYSIS AND CALORIFIC VALUE OF OILS (*C. E. Lucke*)

	Density at 60° or 70° F.		Ultimate Analysis				Heating Value B.T.U. per lb.	
	Sp. gr.	°Bé.	C	H_2	O_2+N_2	S	High	Low
California fuel	.966	14.93	81.52	11.61	6.92	.55	18,926	17,903
Texas, Beaumont fuel	.926	21.25	83.26	12.41	3.83	.50	19,654	18,570
California crude	.957	16.24	86.30	16.70		.80	21,723	21,254
Texas, Beaumont crude	.924	21.56	84.60	10.90	2.87	1.63	18,977	18,025
Pennsylvania crude	.914	23.18	86.10	13.90		.06	20,949	19,735
Kansas crude	.866	31.67	85.40	13.07			20,345	19,203
West Virginia crude	.841	36.47	84.30	14.10	1.6		20,809	19,578
Ohio crude	.829	38.89	85.00	13.80	.6	.6	20,752	19,547

Heating Value.—The heat value for oil usually given is the high heat value, as determined in a bomb calorimeter. The actual heat value available in a boiler furnace is less, because all oil fuel contains a considerable percentage of hydrogen, and the latent heat of the steam formed by combustion passes up the stack as waste heat. The variation in volatility has little effect on the heating value, for the ratio of carbon to hydrogen varies but slightly in the various distillates.

W. Inchley gives an empirical formula for heating value of oils.

$$\text{BTU per lb.} = 13{,}500\ C + 60{,}890\ H$$

wherein C and H denote respectively the proportions by weight of carbon and hydrogen in the fuel.

Another formula by *Sherman* and *Kropff*, based on the fact that the heating value of oil varies with the density, is:

$$\text{BTU per lb.} = 18{,}650 + 40\ (\text{degs. Baumé} - 10)$$

Lucke says that the accuracy of the estimation by the Sherman and Kropff formula is quite good and is probably better than can be obtained from an ultimate analysis.

Storage.—The storage tank should hold at least a carload of oil. A popular size is a 10,000-gallon tank, 8 ft. in diameter and 30 ft. long. The tank should be equipped with a manhole, an opening for filling pipe, a suction opening, a vent opening, and an opening for steam heating coil connections. Insurance requirements call for the tank to be below the level of the pump and boilers. It should be not less than 50 ft. from the nearest building. Because of its fluid nature, fuel oil is easily metered. See page 270.

OIL VS. COAL

In addition to its low price in some localities, the advantages claimed for oil are as follows:

1. Handling cost is low.
2. General labor is saved, by the elimination of stokers, coal passers, etc.
3. The storage can be at a distance from the boiler. Oil occupies 50% less space, and has 25% less weight than coal for equal heat values.
4. More perfect combustion is obtainable, since the air can be better controlled, and there is no loss of combustible in the ash. High efficiency results.
5. Smoke may be eliminated.
6. The intensity of the fire can be instantly regulated to meet fluctuating loads.

7. No loss in calorific value or disintegration in storage.
8. Oil is cleanly and free from dust, saving wear on machinery.
9. Smaller stack is required than for coal.
10. There is no loss from banking fires.

The disadvantages of oil as compared with coal are:

1. The necessity that an oil have a high flash point, to minimize danger of explosions.
2. Ordinances relative to location of storage tanks may make cost prohibitive.
3. Unless furnaces are adapted for oil, the upkeep will be higher.

The Sante Fe Railroad found the evaporative value of coal and oil the same when the price of the coal in tons was 3½ times the price of oil in barrels.

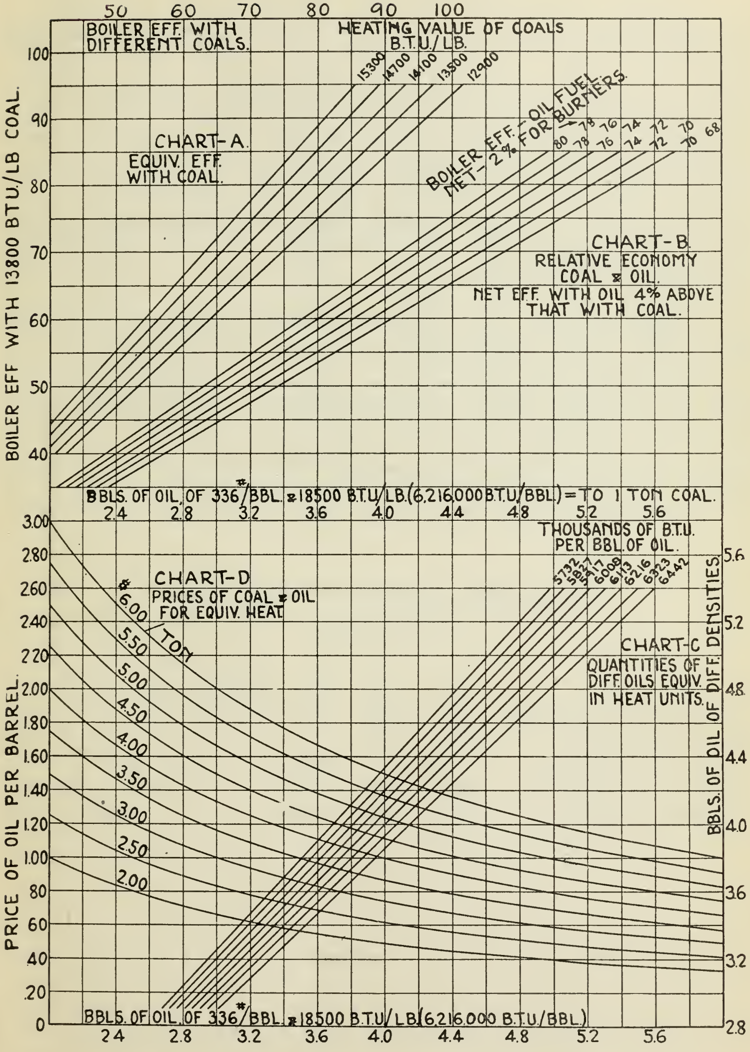
Nelson says that with oil of 19,500 heat units, an evaporation of 14.5 lbs. per pound of oil should be readily obtained, if the apparatus is suitable. With good grades of coal, 8 lbs. evaporation is an average figure. A ton of coal is therefore the equivalent in practical heating value of 3⅓ barrels of oil.

Owing to the higher efficiencies and economies obtainable with oil than with coal fuel, it is found that on the average about 84 heat units from oil are the equivalent of 100 heat units from coal so far as service evaporation is concerned. It has been stated that, including labor costs, the use of oil will result in operating economy up to a price per BTU 36% in excess of that for coal.

The price to be paid for oil and coal for the same evaporative results can be obtained from the charts on page 63, drawn from data supplied by *C. C. Moore & Co.* They are based only on the cost of the two fuels, and consideration must be given to the relative cost of handling both the fuel and the refuse. It can be said conservatively that, under the same steaming conditions oil will give about 4% higher net boiler efficiency than will coal. Charts *B* and *D* refer to a coal of 13,800 BTU heat value, and an oil of 18,500 BTU per lb. heat value and 336 lbs. per barrel. Charts *A* and *C* are used for coals and oils of other heating values.

Assuming a coal costing $4.50 a ton, with a value of 13,800 BTU and giving a boiler efficiency of 65%, if the efficiency obtainable with an oil of 18,500 BTU heat value is not known, it can safely be assumed that the net efficiency will be 4% greater, or 69%. On chart *B* follow the horizontal for 65% efficiency with coal to the diagonal of 69% net efficiency with oil (using the upper row of figures). 4.3 barrels of this oil is found to be equivalent to a ton of coal. On chart *D* follow the vertical for 4.3 barrels till it meets the $4.50 line for coal. The equivalent price for oil will then be $1.04 per barrel. If oil could be purchased for anything less than this, the fuel expense would be decreased by changing over.

Assume a coal of 14,400 BTU, giving an efficiency of 70%, and an oil having a heat value of 6,323,000 BTU per barrel. On chart *A* follow the vertical corresponding to 70% efficiency for coal till it intersects the diagonal of 14,400 BTU for coal. The intersection comes on the horizontal for 73%, which is the equivalent efficiency of coal of 13,800 BTU. Use this on chart *B* as before, assuming 4% greater net efficiency with oil. 4.33 barrels of oil of 18,500 BTU per lb., or 6,216,000 BTU per barrel are found to be equivalent to one ton of coal. On chart *C* follow the vertical for 4.33 barrels to the diagonal for oil of 6,323,000 BTU per barrel, obtaining 4.25 barrels of oil equivalent to one ton of the given coal. From chart *D*, using the vertical for 4.25 barrels, as the coal costs $4.50 per ton, $1.06 per barrel would be equivalent for the given oil.



COMPARISON OF FUEL COSTS FOR OIL AND COAL

C. C. Moore & Co.

GASEOUS FUELS

The gaseous fuels used under steam boilers are natural gas, waste gas from blast furnaces, coke oven gas and producer gas. Natural gas, like mineral oil, is chiefly a mixture of hydrocarbons, but no great complexity exists, as few are gaseous at ordinary temperatures. Accordingly natural gas is fairly definite in analysis, consisting almost entirely of methane, CH_4. Natural gases contain varying amounts of CO, CO_2 and nitrogen, formed no doubt from the action of oxygen on the carbon, the nitrogen accompanying the oxygen. Some natural gases contain higher hydrocarbons, such as ethylene, which are vapors. These have high illuminating value and are sometimes recovered by compression. Blast furnace and producer gases contain large percentages of nitrogen and carbon dioxide, while coke oven gas contains much more combustible.

Gas fuels offer all the advantages of liquid fuels, and but few of the disadvantages.

Artificial gases for steam purposes are usually prohibitive in cost, and even in blast furnace installations the gas engine frequently takes the place of a gas-burning steam installation.

The calorific value of a gas can be more readily predicted than that of coals and oils, since each of its constituents has a known calorific power. The calorific value per unit volume is the sum of the proportions by volume of each of the constituents multiplied by their calorific powers per unit volume. There will be both a high and a low calorific value, owing to the presence of hydrogen. The accompanying table shows the compositions and calorific values of representative natural, blast furnace, producer, and by-product coke gases.

Volumetric Analysis of Fuel Gases

(*C. E. Lucke*)

	CO	H_2	CH_4	C_2H_4	C_6H_6	O_2	CO_2	N_2
Coke Oven Gas (average)..	6.0	42.0	34.3	2.0	2.0	1.1	2.5	10.1
Blast Furnace Gas........	27.5	3.0					10.0	59.5
Natural Gas (Kansas).....	.25		98.2		.1	.25		
Anthracite Producer......	25.7	15.3	.2			.40	5.5	52.9
Bituminous Producer......	14.34	2.81	5.56			.10	10.5	66.7

Air for Combustion and Low Calorific Values of Gases and Fuel Gases as Given in the Table Opposite

(*C. E. Lucke*)

(32° F. and 29.92 Ins. Mercury).

	Specific Weight lbs. per cu. ft.	Specific Volume cu. ft. per lb.	Theoretical Air for Combustion		Heating Value	
			cu. ft. per cu ft. gas	lbs. per lb. of gas	B.T.U. per lb.	B.T.U. per cu. ft.
Carbon Monoxide CO	.07807	12.8090	2.39	2.470	4369	341
Hydrogen H_2	.00562	177.9093	2.39	34.320	51892	292
Methane CH_4	.04470	22.3490	9.56	17.244	21463	959
Ethylene C_2H_4	.07951	12.5780	14.34	14.557	20053	1595
Benzene C_6H_6	.21930	4.5600	35.85	13.194	17305	3795
Coke Oven Gas	.04031	24.8070	5.43	10.872	14384	580
Blast Furnace Gas	.08049	12.4239	.729	.731	1274	103
Natural Gas (Kansas)	.04460	22.4200	9.397	17.004	21301	950
Anthracite Producer	.06954	14.3810	.999	1.159	1929	134
Bituminous Producer	.07902	12.6540	.937	1.059	1397	110

Section II—Combustion

Combustible.—The portion of a substance which combines with oxygen is the *combustible*. In steam practice, the term combustible is applied to that portion of the fuel remaining after subtracting moisture and ash. Thus it may include some oxygen and nitrogen.

Perfect Combustion.—Combustion is perfect when the combustibles unite with the greatest possible amount of oxygen, in the case of carbon, when it burns to CO_2. Combustion is imperfect when complete oxidation of the combustible does not occur, that is, in the case of carbon, when it burns to CO.

The combustion of 1 lb. of carbon (C) by means of pure oxygen (O) to carbon dioxide (CO_2) generates 3⅔ lb. of gas (see page 68) and liberates 14,544 BTU.

The combustion of 1 lb. C to CO_2 by means of air generates 12.52 lb. of gas, the excess over 3⅔ lb. consisting of inert nitrogen (N).

The combustion of 1 lb. C to carbon monoxide (CO) by means of pure oxygen generates 2⅓ lb. of gas and liberates 4,351 BTU.

The combustion of CO to CO_2 liberates $14{,}544 - 4{,}351 = 10{,}193$ BTU per lb. of *carbon* involved, or $\frac{12}{12+16} \times 10{,}193 = 4{,}368$ BTU per lb. of CO.

The reduction of CO_2 to CO absorbs $14{,}544 - (2 \times 4{,}351) = 5{,}842$ BTU per lb. of carbon in the CO_2 or $\frac{5{,}842}{2} = 2{,}921$ BTU per lb. C in the CO produced.

The combustion of 1 lb. hydrogen (H_2) to 9 lb. of water (H_2O) liberates 61,200 BTU if the products of combustion be condensed to water at 64° F. (assumed to be the original temperature of the H_2 and the O_2). If the H_2 and O_2 be assumed to have an initial temperature of 212° F. and the product to be water vapor at 212° F. the heat of combustion is 51,892 BTU, commonly known as the "low" value.

If the H_2 and O_2 are at 212° F. and the product is condensed to water at 212° F., the heat liberated is 60,626 BTU, known as the "high" value.

The dissociation of 1 lb. of water (H_2O) to H_2 and O_2 absorbs

$$\frac{2}{2+16} \times 60{,}626 = 6{,}736 \text{ BTU.},$$

212° F. being the initial and final temperature.

The calculation of the maximum temperature obtainable by burning a given fuel obviously depends upon the heat capacity of the products of combustion. It cannot be calculated by dividing the total heat introduced into and liberated in the furnace with the fuel and air of combustion by any one value of the specific heat of the products of combustion multiplied by their weight, since the specific heat varies with temperature. A better method is to use the total heat capacities of the products of combustion at various temperatures, as given under "Temperature of Combustion," page 103.

The events in complete combustion of coal may be described briefly as follows: The coal, containing moisture, enters the furnace, where the moisture is first driven off. This is accomplished in a very short time, almost completely by the time the temperature of the coal reaches 212° F. As the temperature increases further, the volatile constituents come off. If the temperature at the point of liberation is high enough and oxygen is present, they burn in the space above the fuel bed, approximately as fast as they are distilled. The volatile constituents are not all driven off at the same temperature, so that this operation extends over an appreciable time. At about the time the volatile has all been driven off, the coal has reached a temperature sufficiently high to ignite the fixed carbon. This requires a considerable time, and a higher temperature than the burning of the volatile.

AIR THEORETICALLY REQUIRED FOR COMBUSTION

The study of combustion requires a knowledge of the properties of air. Air is a mechanical mixture of 20.91% oxygen and 79.09% nitrogen by volume. By weight, air contains 23.15% oxygen, and 76.85% nitrogen. In nature, besides oxygen and nitrogen, air contains carbon dioxide, dust, ozone, water vapor and other gases in slight amounts.

The weight and volume of air can be computed from the formula

$VP = 53.4T$, wherein
V = volume in cu. ft. of 1 lb. of air.
P = absolute pressure in lbs. per sq. ft. (atmospheric pressure = 14.7 lb. per sq. in.)
T = absolute temperature, Fahr. = temperature Fahr. + 459.6.
$1/V$ = weight of 1 cu. ft. of air.

By changing the constant, this formula can be used for other gases, 48.24

VOLUME AND WEIGHT OF AIR AT ATMOSPHERIC PRESSURE (14.7 LBS. PER SQUARE INCH) AT VARIOUS TEMPERATURES.—*From Steam.*

Temperature Degrees Fahrenheit	Volume One Pound in Cubic Feet	Weight One Cubic Foot in Pounds	Temperature Degrees Fahrenheit	Volume One Pound in Cubic Feet	Weight One Cubic Foot in Pounds	Temperature Degrees Fahrenheit	Volume One Pound in Cubic Feet	Weight One Cubic Foot in Pounds
32	12.390	.080710	160	15.615	.064041	340	20.151	.049625
50	12.843	.077863	170	15.867	.063024	360	20.655	.048414
55	12.969	.077107	180	16.119	.062039	380	21.159	.047261
60	13.095	.076365	190	16.371	.061084	400	21.663	.046162
65	13.221	.075637	200	16.623	.060158	425	22.293	.044857
70	13.347	.074929	210	16.875	.059259	450	22.923	.043624
75	13.473	.074223	212	16.925	.059084	475	23.554	.042456
80	13.599	.073535	220	17.127	.058388	500	24.184	.041350
85	13.725	.072860	230	17.379	.057511	525	24.814	.040300
90	13.851	.072197	240	17.631	.056718	550	25.444	.039302
95	13.977	.071546	250	17.883	.055919	575	26.074	.038353
100	14.103	.070907	260	18.135	.055142	600	26.704	.037448
110	14.355	.069662	270	18.387	.054386	650	27.964	.035761
120	14.607	.068460	280	18.639	.053651	700	29.224	.034219
130	14.859	.067300	290	18.891	.052938	750	30.484	.032804
140	15.111	.066177	300	19.143	.052239	800	31.744	.031502
150	15.363	.065092	320	19.647	.050898	850	33.004	.030299

for oxygen, 54.97 for nitrogen, 765.71 for hydrogen, 35.09 for CO_2, 55.14 for CO and 24.10 for SO_2. The table below is computed from this formula.

To determine the weight per cu. ft. of air or flue gases at other temperatures than 32° and 29.92 in. Mercury, use for air

weight per cu. ft. $= .0807 \frac{492}{T^\circ}$ and for gases $.084 \frac{492}{T^\circ}$, wherein T° is the absolute temperature Fahr.

One pound of pure carbon requires for its combustion 2.67 lb. of oxygen, or 32 cu. ft. at 60° F. The gaseous products of combustion, when cooled, will occupy the same volume as the original oxygen, namely 32 cu. ft., and will weigh 3.67 lb. Nitrogen in air used for combustion undergoes no change, and occupies its original volume.

The table on page 69, from *Steam*, gives the weights of oxygen and air theoretically required for the combustion of the combustible constituents of coal. As an example of the calculation of these quantities, consider the reaction $C + O_2 = CO_2$.

Molecular weights $12 + 32 = 44$.

1 lb. of C requires $32/12 = 2\text{-}2/3$ lb. of O to form $44/12 = 3\text{-}2/3$ lb. of CO_2. Ratio N/O in air $= 3.32$, therefore the nitrogen accompanying the oxygen of air required to burn one pound of carbon is $2\text{-}2/3 \times 3.32 = 8.85$ lb., and the total weight of air for 1 lb. of carbon is 11.52 lb.

The table also gives the heat energy generated by the complete combustion of one pound of the combustible constituents.

The theoretical amount of air required for the complete combustion of coal can be computed from the formula

$$\text{Weight of air per lb. of coal} = 11.52C + 34.56\left(H - \frac{O}{8}\right) + 4.32S,$$

C, H, O and S being the proportional parts by weight of carbon, hydrogen, oxygen and sulphur from the ultimate analysis of the coal.

Hydrogen combines with eight times its weight of oxygen, therefore it is assumed that hydrogen equivalent in weight to one-eighth of the oxygen in the coal will not require oxygen from the air.

The following slightly different formula is used by the *Bureau of Mines* for computing the air theoretically required for burning one pound of combustible:

$$A_r = 34.48H + 11.58C + 4.336\,(S - O)$$

H, C, S and O are proportions based on coal free from moisture and ash. These formulæ are somewhat inexact, because they contain no correction for the nitrogen in the coal.

Complete combustion is not obtained in boiler furnaces receiving only the amount of air theoretically required. 30 to 50% above that theoretically required, or 16 to 18 lb. of air per pound of fuel, is necessary to insure perfect combustion, but in only a very few plants is the air supply maintained at this point. It is often found to run from 100 to 200 or 400% excess, entailing great loss of heat in the hot chimney gases.

J. Azbe points out the inaccuracy of the current statement that approximately 12 lb. of air are theoretically required per pound of coal. The table on page 70 shows that one coal may require only 7 lbs. of air, while another would require 11.2 lbs. of air per pound. However, with different coals approximately the same quantity of air is required for liberating a given quantity of heat. He suggests the expression "pounds of air per 10,000 BTU." Coal requires something over 7½ lbs. of air per 10,000 BTU liberated.

OXYGEN AND AIR REQUIRED FOR COMBUSTION, AT 32 DEGS. F., AND 29.92 INCHES OF MERCURY AIR PRESSURE.—*Steam.*

BY WEIGHT

1	2	3	4	5	6	7	8	9	10
Oxidizable Substance or Combustible	Chemical Symbol	Atomic or Combining Weight	Chemical Reaction	Product of Combustion	Oxygen per Pound of Column 1 Pounds	Nitrogen per Pound of Column 1 = 332* x O Pounds	Air per Pound of Column 1 = 4.32† x O Pounds	Gaseous Product per Pound of Column 1 = 1 + Column 8 Pounds	Heat Value per Pound of Column 1 B. t. u.
Carbon	C	12	$C+2O=CO_2$	Carbon Dioxide .	2.667	8.85	11.52	12.52	14600
Carbon	C	12	$C+O=CO$	Carbon Monoxide	1.333	4.43	5.76	6.76	4450
Carbon Monoxide	CO	28	$CO+O=CO_2$	Carbon Dioxide .	.571	1.90	2.47	3.47	10150‡
Hydrogen . . .	H	1	$2H+O=H_2O$	Water	8	26.56	34.56	35.56	62000
Methane . . .	CH_4	16	$CH_4+4O = CO_2+2H_2O$	Carbon Dioxide and Water . .	4	13.28	17.28	18.28	23550
Sulphur. . . .	S	32	$S+2O=SO_2$	Sulphur Dioxide .	1	3.32	4.32	5.32	4050

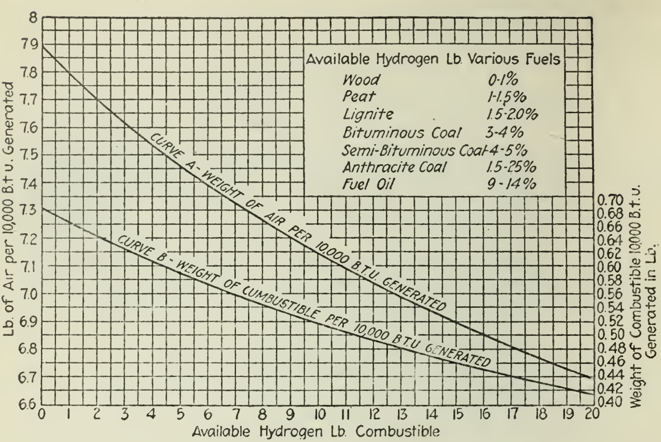
BY VOLUME

1	2	11	12	13	14	15	16	17	18
Oxidizable Substance or Combustible	Chemical Symbol	Volumes of Column 1 Entering Combination Volume	Volumes of Oxygen Combining with Column 11 Volume	Volumes of Product Formed Volume	Volume per Pound of Column 1 in Gaseous Form Cubic Feet	Volume of Oxygen per Pound of Column 1 Cubic Feet	Volume of Products of Combustion per Pound of Column 1 Cubic Feet	Volume of Nitrogen per Pound of Column 1 = 3.782§ x Column 15 Cubic Feet	Volume of Gas per Pound of Column 1 = Column 16 + Column 17 Cubic Feet
Carbon	C	1C	2	$2CO_2$	14.95	29.89	29.89	112.98	142.87
Carbon	C	1C	1	2CO	14.95	14.95	29.89	56.49	86.38
Carbon Monoxide	CO	2CO	1	$2CO_2$	12.80	6.40	12.80	24.20	37.00
Hydrogen . . .	H	2H	1	$2H_2O$	179.32	89.66	179.32	339.09	518.41
Methane . . .	CH_4	1C 4H	4	$1CO\ 2H_2O$	22.41	44.83	67.34	169.55	236.89
Sulphur. . . .	S	1S	2	$1SO_4$	5.60	11.21	11.21	42.39	53.60

* Ratio by weight of O to N in air.
† 4.32 pounds of air contains one pound of O.
‡ Per pound of C in the CO.
§ Ratio by volume of O to N in air.

(The chemistry of columns 4, 11 and 12 above is open to question, as C is not a gas and it is not proper to speak of its volume as a gas; hydrogen gas exists as H_2, not as H, and oxygen as O_2, not O.—*Ed.*)

The chart on page 70 shows the weight of air required to generate 10,000 BTU with fuels of different hydrogen content. The abscissæ are percents of available hydrogen per pound of combustible. The available hydrogen is the percent of hydrogen less one-eighth of the percent of oxygen. This, divided by the percent of combustible, is equal to the percent available hydrogen per pound of combustible. The percent available hydrogen per pound of combustible in commercial coals runs from about 2½ to 5. The calculations for the curve disregard sulphur, since its percentage is small. The second curve gives the weight of combustible to generate 10,000 BTU. The weight of air theoretically required per pound of fuel can be obtained by multiplying the heating value of the fuel by the weight of air theoretically required to generate 10,000 BTU, as obtained from the curve, and dividing by 10,000.



THEORETICAL AIR AND COMBUSTIBLE PER 10,000 B. T. U.

The weight of air theoretically required for the complete combustion of one pound of coal can be obtained from the chart on page 164, in the section on "Air Requirements and Supply." The curve for zero percent excess air gives the weight of air theoretically required per pound of combustible for coals of varying hydrogen content. To obtain the air theoretically required per pound of coal, multiply by the percentage of combustible in the coal. This curve also gives the maximum percentage of CO_2 obtainable in the flue gases with coals of varying hydrogen content.

AIR REQUIRED FOR DIFFERENT FUELS

	Air theoretically required per lb. of coal	Air theoretically required per 10,000 BTU generated
Illinois bituminous, poor quality	7.0	7.6
Illinois bituminous, good quality	9.4	7.55
Anthracite, average	10.2	7.65
Semi-bituminous, Pocahontas	11.2	7.5
Liquid fuel	14.24	7.04

Mass Action.—The necessity for excess air is partially occasioned by inadequate mixing of the air with the combustible, but also by the appreciable time required for combustion, as explained by the law of mass action. This firmly established and useful law of physical chemistry may be illustrated by the fact that the more water used, the easier it is to dissolve sugar or salt. The law of mass action states that the speed of any chemical reaction is proportional to the product of some powers of the weights expressed in gram molecules of the reacting substances present in unit volume. A gram molecule is a weight numerically equal in grams to the molecular weight of the substance, and the number of gram molecules in a given volume of a substance would be the weight in grams divided by the molecular weight. If one molecule of a substance reacts with two molecules of another substance, the velocity of the reaction will be proportional to the number of gram molecules of the first substance in a unit volume multiplied by the square of the number of gram molecules of the second substance in unit volume. This reaction is of the third order.

The speed of a chemical reaction increases when the weight in gram molecules of the reacting substance in a unit volume increases, although the relation may not be a simple proportion. If there are two molecules of carbon monoxide and ten molecules of oxygen in a unit volume, the chances of one molecule of oxygen meeting the two molecules of carbon monoxide are a great deal more than if there were only one or two molecules of oxygen in the same unit of volume. When, in the mixture of air and furnace gases, some of the oxygen unites with carbon monoxide, this oxygen is no longer available for oxidizing the remaining combustible. The products of combustion are in the way and fewer oxygen and carbon monoxide molecules are left, so that the molecules of oxygen meet the molecules of combustible gas less frequently. As the combustion proceeds, the masses of free oxygen and combustible gas become less and less compared with the total mass of gas present and their combination becomes slower until it is nearly zero. Were the air supply in the ordinary furnace limited to the theoretical amount, the reaction would take so long, assuming the present gas mixing arrangements, that the gases would have passed through the furnace before completing combustion.

Fifty-six parts by weight of carbon monoxide (twice its molecular weight) combine with 32 parts by weight of oxygen (its molecular weight), two molecules of carbon monoxide and one molecule of oxygen combining to form two molecules of carbon dioxide. The weights of equal volumes of gases are directly proportional to their molecular weights, as the same volume of all gases at the same temperature and pressure contains the same number of molecules. In applying the law of mass action, by substituting the volumetric percentages of the substances, as ordinarily given in gas analyses, in the mass-action equation corresponding to the particular reaction, we obtain a relative indication of the rate of combustion, assuming the same pressure and the same temperature in every case. For the combining of CO with O_2, the relative rate of combustion is given by the equation

$$\text{rate of combustion} = \text{constant} \times (\text{gram molecules of CO per cu. meter})^2 \times (\text{gram molecules of } O_2 \text{ per cu. meter}).$$

By taking the analyses of gases from different points in the gas passage, from the fuel bed to the end of the combustion chamber, the relative rates of combustion at the different points in the combustion chamber can be determined.

However, calculations of velocities of reaction based on the laws of mass action are liable to be seriously in error owing to disturbing side reactions. If more than one combustible is present, the two reactions go on independently side by side and the effects are added. Care must be taken not to add these velocity products without having first multiplied each by its proper reduction factor, which for most substances is imperfectly known for high temperatures. Therefore it is not feasible at present to get an expression for the absolute total velocities of combustion for all constituents taken together at several points along the flame.

The law of mass action also applies to the combustion of the fixed carbon on the grate. The mass of solid carbon is almost infinite in comparison with that of the gaseous oxygen, so that the velocity of combustion depends to a large extent upon the rate of diffusion. That is, there is a layer of CO next to the carbon; and combustion can take place only so fast as this can be reached by O_2. Part of the resulting CO_2 escapes and part breaks down to CO again by contact with the hot carbon. Scrubbing action, due to the velocity of the gases, promotes the interchange of O_2 and CO_2 and accelerates the combustion; note for example how much more rapidly coal burns at a thin spot or over the end of a tuyere where the air velocity is great. Obviously diffusion plays a part in the combustion of both gases and solids.

The speed of chemical reactions also increases at a rapidly increasing but not definitely known rate as the temperature is increased. There is some combustion even at ordinary atmospheric temperatures, which if the resulting heat is confined, may cause a high temperature and give rise to so-called spontaneous combustion. At high furnace temperatures, the rate of combustion is enormously increased for both gases and solids.

GRATES AND GRATE SURFACE

The purpose of the grate is to support the fuel bed, while at the same time admitting air for combustion. It should be so designed that it will be kept uniformly cool by the inflow of air and that it will void ashes freely at all points. The width of air space is determined by the coal for which the grate is to be used. It should be as wide as possible while not allowing the coal to drop through.

Authorities differ as to the proper width of air space. *Gebhardt* says that for average bituminous coal the air space should be ⅝ in. wide, and the bars ¾ in. Air openings in grate bars should be 3/16 in. wide for No. 3 Buckwheat, and 5/16 in. for No. 1 Buckwheat. It is important that they be uniformly distributed, to avoid blowing holes in the fire.

The physical ability of the fireman limits the depth of the grate surface for hand firing. The handling of a soft coal fire is more difficult, and therefore the grates cannot be as deep as for anthracite. Grates 10 to 12 feet deep, with a slope of 1½ inches per foot, can be handled with buckwheat.

Grate area has usually been determined arbitrarily in proportion to the heating surface of the boiler, that is, for a given size of coal the heating surface and the grate surface have had a fixed ratio. The following figures for anthracite and the table for bituminous coal are given to show usual practice:

A ratio of grate surface to heating surface of 1 to 35 or 40 will develop the rated capacity of the boiler when burning buckwheat. For finer sizes, or for overloads, the ratio should preferably be 1 to 25, and forced draft should be used.

The following table is given by *Marks* for the grate proportions for burning various bituminous coals:

Coal	Grate bar openings Mine run	 Slack	Ratio for economy Mine run	 Slack	Ratio for capacity Mine run	 Slack
Va., W. Va., Md., Pa.	½	⅜	1:60	1:55	1:55	1:50
Ohio, Ky., Tenn., Ala.	⅜—½	¼	1:55	1:50	1:50	1:45
Ill., Ind., Kan., Okla.	⅜—½	¼	1:50	1:45	1:45	1:40
Col. and Wyo.	⅜	¼	1:50	1:45	1:45	1:40

In determining the amount of grate surface to be used with a given amount of heating surface, the draft available must be considered as well as the coal. The curves given on page 114 show how much draft is necessary for burning different coals at different rates of combustion.

The draft required to overcome the resistance of any type of boilers is also known fairly closely (see page 112). This must be subtracted from the total draft available, to determine the draft available for the fuel bed. For any given type of boiler the overall efficiency can be approximately assumed. Knowing the capacity of the boiler, the number of heat units, and therefore the number of pounds of a given coal required per hour, can be obtained. Dividing the number of pounds of coal which must be burned per hour by the rate of combustion taken from the curve, gives the total grate area required in square feet.

The comparatively small amount of difference in the amount of fixed carbon burned per unit of grate surface with all kinds of coal under equal operating conditions is surprising. *A. A. Carey* prefers to burn from 12 to 16 lb. of fixed carbon per sq. ft. of hand fired grate surface per hour, with chimney draft. Roughly the rates of combustion for different fuels would be:

Anthracite, 15 lb. per sq. ft. per hour.
Semi-anthracite, 16 lb. per sq. ft. per hour.
Semi-bituminous, 18 lb. per sq. ft. per hour.
Eastern bituminous, 20 lb. per sq. ft. per hour.
Western bituminous, 30 lb. per sq. ft. per hour.

HAND FIRING

There are two general methods of hand firing:

In the spreading method, sometimes called the alternate method, a small amount of coal is fired at one time, and spread evenly over the fuel bed from the front to rear. The firing is done alternately through the fire doors, so that the entire fire is not blanketed with green coal. Hand firing practice leans more and more to spread firing.

In some tests on a furnace equipped with three firing doors, the *Bureau of Mines* used the following spreading method: The rear half of the section of grate fired through doors 1 and 3 and the front half of the section fired through door 2, were fired at the same time. At the next firing, the front half of the section of grate fired through doors 1 and 3 and the rear half of that fired through door 2 were fired.

In the coking method, fresh coal is fired at considerable depths at the front of the grates, and when nearly or wholly coked, is pushed to the back of the furnace. The object is to maintain a bed of incandescent carbon at the rear of the grate, in passing over which the volatile from the green coal at the front will be burned. This method is particularly adapted to furnaces wherein gases pass horizontally over the fire.

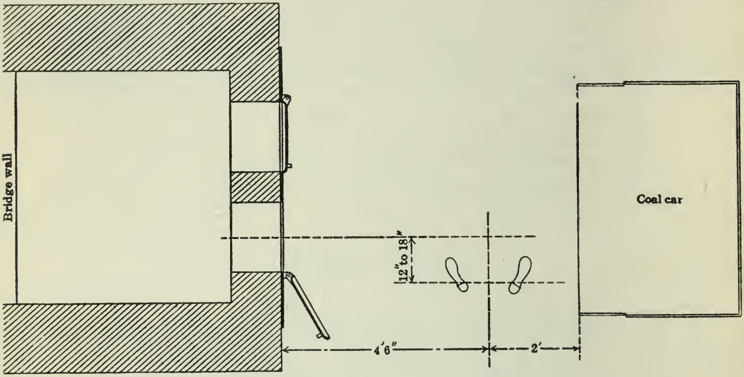
Before each firing the coked fuel is pushed back, leaving about one-third of the grate bare and all of the green fuel is fired on the bare grate. The fire door is cracked slightly to admit air for the volatile gases.

Comments on Spreading Method.—The spreading or alternate method of firing gives higher efficiency, higher CO_2, lower temperature of exit gases and generates steam more uniformly than does the coking method, due to more uniformity in furnace temperature.

The *Bureau of Mines* states that about the same amount of slicing and raking is required in either coking or spreading methods (of course excluding in this the leveling required in the coking method).

Comments on Coking Method.—According to the *Bureau of Mines* the coking method of firing produces less clinker, since the leveling of the fire at the firing period shakes more ash through the grate, and lower CO_2, due to longer firing period, results, with a tendency to admit excess air through the thin spots. The analysis of ash shows no difference in the amount of combustible for the two methods of firing.

Hays says that the coking method is impossible with a fluctuating load. Holes that cannot be seen develop in the rear of the fuel bed. The coking method is a good smoke preventer, but experience is required before it can be used without loss of efficiency.



A PROPER POSITION FOR FIRING THE FURNACE

STANDARD PRACTICE FOR HAND FIRING

The following procedure in firing is recommended by the *Bureau of Mines:*

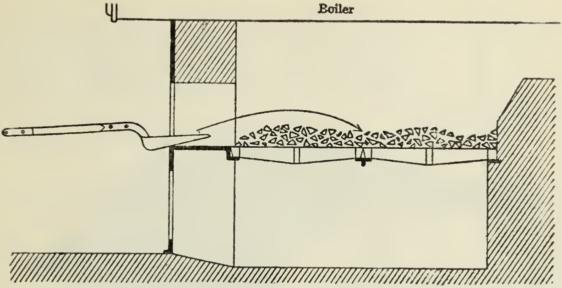
The fireman must take a proper position so that he can see the thin spots and can throw the coal onto them with the least effort. He should stand 4½ to 5 ft. in front of the furnace, and 12 to 18 in. to the left of the center line of the door. He should then be about 2 ft. from the coal, which is 6 or 7 ft. from the furnace front and should preferably be on a car.

The scoop should travel in a nearly straight line. At the end of the throw, the scoop should suddenly be stopped by laying it on the bottom edge of the door frame. The coal then flies off and is scattered over the proper spot. By thus stopping the scoop, the fireman saves effort, and locates the coal better. If he pushes the scoop way into the furnace, he has to jerk it back to get the coal off.

Hand-firing is hard work, and requires considerable judgment and skill. There should be sufficient firing space for handling the shovel and tools.

If the coal is closer than 6 or 7 ft., the fireman is crowded and will stand away to one side of the door to avoid the intense heat. He cannot see the fire, and throws the coal in by guess. His scoop travels in the arc of a circle, scattering coal on the floor, and dumping it in a heap directly inside of the door. This results in an uneven fire, low efficiency, and requires raking of the coal onto the back part of the fire.

Provide a smooth firing floor, or a smooth bottom to the coal car, so that the shovel does not hit bumps and rivets. Such items delay the firing operation, keeping the door open longer than necessary and admitting an excess of air.

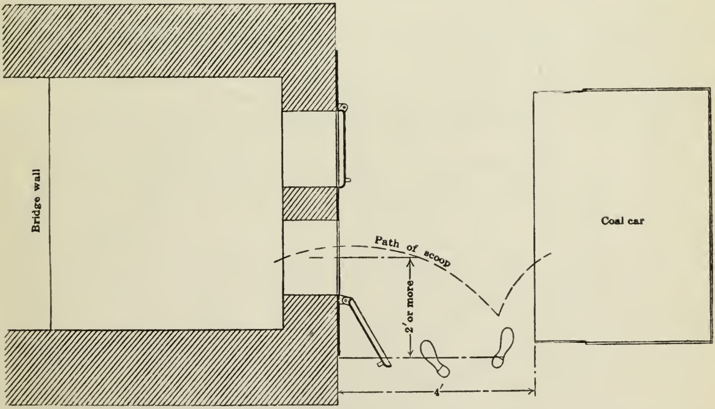


THE END OF THE THROW

The scoop is stopped by laying it on the lower edge of the fire door frame and the coal, following the course of the arrow, slides off the scoop and falls on a thin spot in the fuel bed.

Hays says that about 1% of coal is lost in the average plant due to waste in handling at the plant. Coal is thrown on the floor and ground to dust by feet and wheels, and mixed with ash.

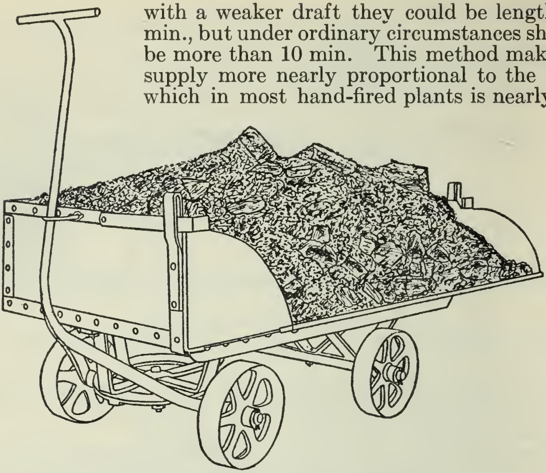
The *Bureau of Mines* recommends burning coal rapidly and at high temperatures in order to secure the best available economy. Fire small quantities of coal at short intervals, so that thin places do not burn through and admit large excess of air. The quantity depends on the grate size and the draft. With a draft of 1 in. in the uptake, 2 to 2½ lb. per square foot of grate is a good average. Thus, on a grate 6 by 8 ft., 100 to 125 lb. of coal, or about 6 to 9 shovelfuls, would be the quantity for one firing. The intervals should be about 5 min. For a higher draft, the periods could be 3 min.,



IMPROPER POSITION FOR FIRING

The fireman stands too near to the furnace and too far to one side. He cannot see the surface of the fuel bed and throws the coal in by guess; some of it falls off the scoop before the latter reaches the firing door. The coal car is too near the furnace. The dotted lines show the path of the scoop.

with a weaker draft they could be lengthened to 8 min., but under ordinary circumstances should never be more than 10 min. This method makes the coal supply more nearly proportional to the air supply, which in most hand-fired plants is nearly constant.

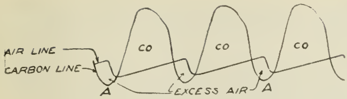


COAL CAR OF A GOOD DESIGN

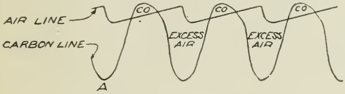
The following are reasons for light and frequent firing: When fresh coal is fired, the volatile matter is immediately distilled. The process is nearly completed in 2 to 5 min., therefore immediately after firing large quantities of air should be admitted over the fire. After 2 to 5 min. it should be cut down. Such regulation is practically impossible. As the air supply is practically constant, immediately after firing it becomes insufficient and incomplete combustion results. After most of the volatile matter has been driven off, the air is in excess. The two losses are much less when small amounts are fired at frequent intervals. Automatic air control devices can be purchased, but even with them frequent and light firing is best. Frequent firing alleviates the tendency to form a crust on top of the fuel bed.

The effects of firing methods on combustion results are illustrated by the diagrams on page 77. The first four figures are modified from sketches by *W. C. Edge.* The second four figures are redrawn from *M. Gensch.* In every case the abscissas are time, and *A* represents the point of firing. In the first four figures the air line represents the relative amounts of air passing through the fuel bed; when the coal is fired the air supply through the fuel bed is immediately cut down and a crust quickly forms by fusion and further cuts down the air. Then, as combustion of the solid part of the fuel proceeds, the fuel bed becomes more porous or holes may burn through, gradually increasing the relative amount of air through the fuel bed until the next firing. The carbon line represents the relative amount of carbon which is in the process of burning. After firing an appreciable time is taken for all of the coal to ignite. After the peaks of the carbon line are reached the amount of incandescent carbon decreases by combustion. When the air line is above the carbon line, excess air is entering the furnace; when the carbon line is above, there is insufficient air and the combustion is incomplete.

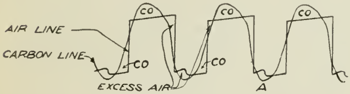
The 5th, 6th and 7th figures represent the relative amounts of air required for coals at different times between firing periods. The last figure represents the rate of heat liberation with firing at long intervals.



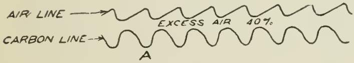
1. HEAVY FIRING AT LONG INTERVALS, DAMPERS CHOKED DOWN



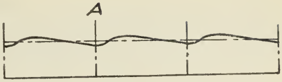
2. HEAVY FIRING AT LONG INTERVALS, DAMPERS OPEN



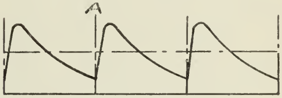
3. HEAVY FIRING, DAMPER REGULATED TO SUIT



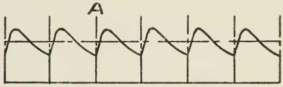
4. METHOD OF CORRECT FIRING, LIGHT AND FREQUENT, DAMPER REGULATED



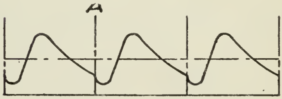
5. AIR REQUIRED FOR BURNING ANTHRACITE



6. AIR REQUIRED FOR BURNING HIGH VOLATILE COALS



7. AIR REQUIRED FOR BURNING HIGH VOLATILE COALS WHEN FIRING PERIODS ARE FREQUENT



8. HEAT LIBERATED FOR USE OF THE BOILER UNDER THE FIRING METHODS OF FIGS. 1 AND 6

The first figure represents heavy firing at long intervals, with the dampers choked down. The air supply is proper for much less than half the time. This is a common occurrence.

The second figure represents the same firing intervals as the first, but with the dampers wide open. This results in a little CO immediately after firing and large amounts of excess air for most of the time. This is also a common condition.

The third figure represents a better method than either the first or second; heavy firing at long intervals. The damper is opened wide soon after the firing periods and is closed down after part of the fuel has burned away.

The fourth figure represents the correct method of firing. Firing is light and frequent. The damper is set so that the load may be carried with the highest CO_2 and no CO.

Figures 1 to 4 apply where secondary air is supplied through holes in the fire. If the secondary air is supplied through dampers in the fire doors, this supply increases after firing, due to higher draft.

The 5th and 6th figures show the relative quantity of air actually required for firing coal at fairly long intervals. The largest amount of air is required soon after firing whereas (see figures 1 and 2) the air supplied at this time is the minimum.

The seventh figure shows the relative quantity of air actually required for firing represented by the fourth figure. The statement in connection with figures 5 and 6 also applies here.

In looking for holes and thin places in the fire, be particular to look in the corners at the front of the furnace, and between the firing doors. Where stokers are used, look to see if there are large air leaks through the coal hopper.

As remarked by the *Bureau of Mines*, a skillful fireman can at a glance estimate the amount of coal required at a given spot. Almost unconsciously he picks the right amount, and selects the right mixture of fine and coarse coal. If the coal is burned way down, he selects coarse coal, to avoid its sifting through the grate. This also permits of the building up of the level on the spot more quickly, as the coal does not tend to fuse so much as slack. Thin and thick spots will occur, even with most careful firing. In places where the air flows freely, the coal burns faster, forming a thin spot. The cause of the variation in air flow may be the difference in the size of the coal, the accumulation of clinker or the fusing of coal into a hard crust. Before firing fresh coal, the fireman should note the thin places. They have bright, hot flames, while high spots have smoky flames or none at all. *Uehling* says to cover the holes, if burned through, with incandescent coal before firing. Place the coal on the thin spots in thin layers. If deep hollows are filled at once, fresh coal may fuse and choke off the air, forming a new high spot. If high spots are missed for one or two firings, they will burn down to normal. If the high spot is due to clinker, the clinker must be removed.

Burning Anthracite.—Fire evenly, in small quantities, at frequent intervals, otherwise dead spots will appear in the fire. If the fire becomes too irregular, burning in patches, nothing can be done but to clean the entire fire. After firing, the fire should be left alone, and the fire tools used as little as possible. Owing to difficulty in igniting, care must be taken in cleaning the fire. Intervals of cleaning depend on the coal and the rate of combustion. With small sizes and moderately high rates of combustion fires will have to be cleaned twice each eight-hour shift. As the fires become dirty, the depth of fuel may be 12 to 14 in.

Burning Bituminous Coal.—The burning of bituminous slack coal is difficult, because it fuses into a hard, tight crust. This admits little air, and therefore the combustion rate is low. The heavier the firing the worse is the condition. Some firemen fire heavy charges of 300 to 500 lb. They break the crust by lifting with the slice bar, and then level the fire. This is satisfactory with coals whose ash does not fuse readily. For coals with a fusible ash, the better method is to keep the fire about 5 in. thick, and fire small charges. The prongs of the rake can be used to break the crust if it does not burn through. The fire should be worked as little as possible, as the working of a fire is liable to cause clinker, furthermore, while the doors are open, excess air is admitted and the fireman has more work.

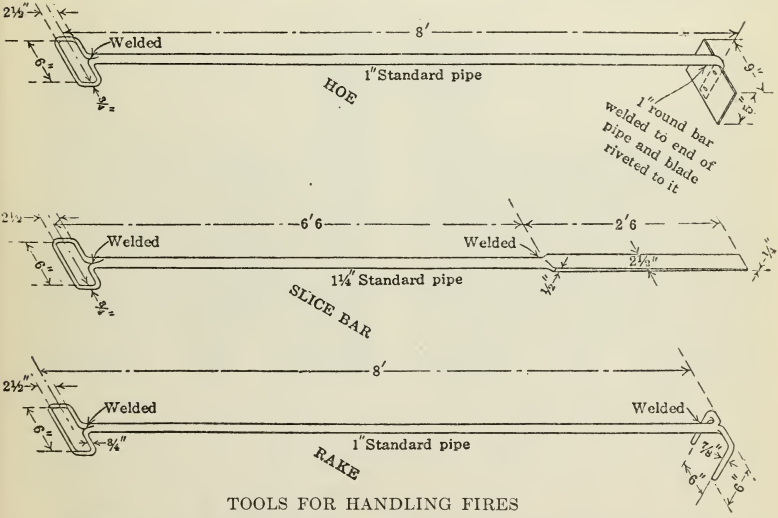
A writer in *Power* recommends burning slack coal in small quantities and evenly spread, not over 5 to 8 in. thick. If the coal has a tendency to cake, slice frequently. Do not lift ash into hot zone. Simply run the slice bar under the fuel and twist slightly with a side movement to open up air holes. A shaking grate with 40% air space is satisfactory. Rock the grate, not violently, when the ash pit grows dark.

Hays says: "Turn the hose on any fine coal-pile. It is impossible to burn some fine coals without wetting them. Fine coal tends to pack in the furnace, especially if dry, or if it contains much ash. If it is wet, the steam generated will tend to loosen it. As a result, more coal will be burned and that more uniformly, with less combustible in the ash, and less combustible carried over by the draft into the combustion chamber. There will be fewer cracks in the fuel bed, and the coal will burn with a great deal less excess of air."

Burning Lignite.—The burning of lignite is more difficult than burning bituminous coals. *Steam* recommends a large combustion space. The best results are obtained with a reverberatory furnace giving long travel to the gases. The fuel bed can be 4 to 6 in. thick. Fire lignite in small quantities by the alternate method. Above certain rates, clinker forms rapidly. Considerable draft should be available, but should be carefully regulated by a damper. Smokelessness with hand firing is practically impossible. There is a strong tendency to foul the heating surfaces, which should be cleaned frequently. Shaking grates assist in cleaning the fire, but considerable fuel may pass through.

Firing doors are opened too frequently when coal is not being fired in order to see the condition of the fire and excess air is admitted. A 1½ in. mica covered peep hole in the door avoids this. The CO_2 percentage was increased by 1½% in one plant by this method.

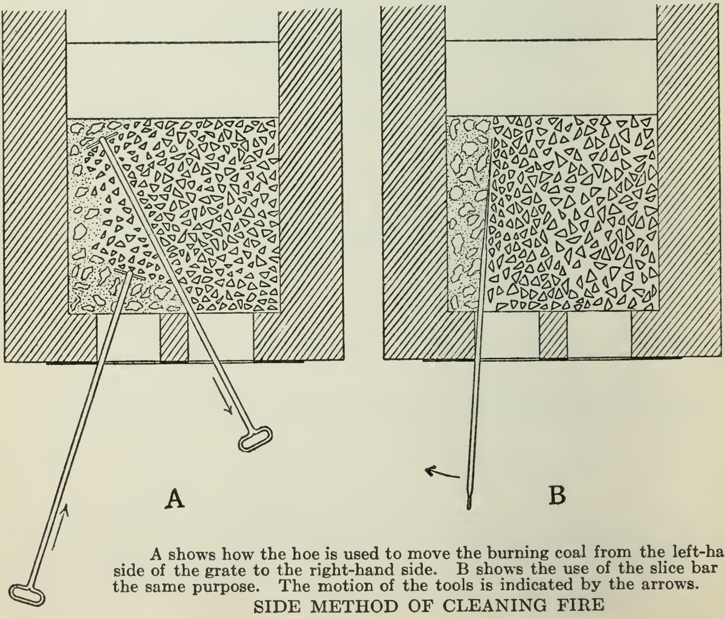
Cleaning Fires.—The tools recommended by the *Bureau of Mines* for handling the fires are illustrated and dimensioned herewith, and the methods of using them are explained in the following paragraphs. The hoe and slice bar are used for cleaning the fire, and the rake for leveling the fuel bed.



TOOLS FOR HANDLING FIRES

Cleaning of the fire is necessitated by the fact that clinker and coarse ash will not pass through the grates. The intervals between cleaning depend upon the proportion of ash in the coal, the character of ash, and the type of the grate. If the coal contains much ash, or ash that is fusible, the fires have to be cleaned often; if light fires are carried, less clinker forms, and under such conditions the fire can often be run through a day shift without cleaning. The cleaning of the fires should be done thoroughly. All the clinker and ash should be removed so that they cannot fuse to the side wall. They should be removed in such a way as to waste very little combustible. There are two methods of cleaning hand-fired furnaces.

In the side method, one side of the fire is cleaned at a time. The good coal is scraped and pushed from one side to the other. The clinkers may have to be removed from the grates by the slice bar. When they have been loosened and broken up, they are scraped out of the furnace with the hoe. The fireman should gather the clinker on the front part of the grate before pulling it out into the wheelbarrow, as this saves him from exposure to the heat. After the one side is cleaned, the burning coal from the other is moved and scraped to the clean side. It is spread evenly over the clean part of the grate, and a few shovelfuls of fresh coal are added, in order to have enough burning coal to cover the entire grate when the cleaning is done. This adding of coal is important, especially when the cleaning must be done with the load on the boiler. The clinkers are then removed from the second half of the grate. When cleaning is started, there should be so much burning coal in the furnace that enough will be left to start a hot fire quickly, when the cleaning is completed. If a light fire is carried, it may be necessary when starting to clean to put some fresh coal on the side to be cleaned last. During cleaning the damper should be partly closed. A fireman after becoming familiar with side method should be able to clean a 200 H.P. boiler furnace in 10 to 12 min.



A shows how the hoe is used to move the burning coal from the left-hand side of the grate to the right-hand side. B shows the use of the slice bar for the same purpose. The motion of the tools is indicated by the arrows.

SIDE METHOD OF CLEANING FIRE

In the front to rear method of cleaning, the burning coal is pushed with the hoe against the bridge wall. It is usually preferable to clean one-half of the grate at a time. The clinker is loosened and pulled out of the furnace and the burning coal is spread evenly over the bare grates. If the front to rear method must be used while the load is on the boiler, the side method should be employed after the day's run is over, so as to prevent the large accumulation of thick and hard clinker at the bridge wall.

Some firemen have the habit of pulling the clinkers out of the furnace without scraping and pushing the burning coal against the bridge wall or to one side. This really is not a method of cleaning the fire. They run a slice bar under the clinker to lift it to the surface of the fuel. Then they take a hoe and pull the large pieces out. The small pieces are not easily detected and are left in the fire. These fuse in a few minutes, due to the high temperature near the surface of the fuel bed, and then run into the grates. Thus more masses of clinker are formed, which are usually worse than those previously removed. This habit should be discouraged.

In cleaning the fire in a plant running morning to noon, and noon to 5.30 P.M., break the clinker at 10.30 A.M., clean the fire at noon, again break the clinker at 4 P.M., and clean again after the day's shift is over. The cleaning of a banked fire should be done about two hours before steam is needed. It is advisable to bank the fire at the front of the grate near one of the doors. This exposes the clinkers, which can be pulled out.

THICKNESS OF FIRE

As stated by the *Bureau of Mines*, the thickness of the fire should vary according to the available draft. (See section on Draft.) With 1 in. draft available at the breeching, firing run of mine coal, a 4 to 8 in. fuel bed is best; the coarser the coal the thicker the bed. A thick fuel bed offers more resistance than a thin one. Therefore with the same available draft, there is less air passed through a thick fuel bed, which means a lower rate of combustion and lower capacity. If difficulty is experienced in maintaining steam pressure with a thick fuel bed, it may be possible to overcome the difficulty by carrying a thinner bed. The objection to a thin fuel bed is that too much air flows through without uniting with carbon, but a thin fuel bed *does not* pass oxygen through unburned unless there are holes in it. Evidence shows that from a fuel bed 3 to 4 in. thick, the gases rising from the surface average less than 2% oxygen, and about 25% combustible gas. As a result, considerable air must be admitted through the fire-doors and other openings to burn the combustible gases. A thick fuel bed does not necessarily decrease the free oxygen in the flue gas, but may actually increase it. Thickening the fuel bed increases the resistance to the passage of air therethrough. The draft, however, does not increase as rapidly as the resistance. As the fuel bed is thickened, less air passes through it, and less combustible gas rises from its surface. The higher draft, however, brings in more air over the fuel bed, resulting in a greater amount of free oxygen in the flue gases. Clinker has the same effect.

An experienced fireman says: "The greater the load, the thinner the fire. To burn a lot of coal you need a lot of air, and the only way you can get it through the fuel bed is to keep the fire thin."

The difficulty of successfully burning bituminous coal increases with the volatile content. The percentage of volatile will affect the required depth of fuel bed.

The following suggestions by *Steam*, while not hard and fast, may be of service in hand-firing bituminous coal, keeping in mind that sufficient draft must be available.

Semi-bituminous coals, Pocahontas, New River, Clearfield, etc., require a 10 to 14 in. fire. Fresh coal should be fired at 10 to 20 min. intervals, and a sufficient amount charged for maintaining a uniform thickness of fuel bed.

Pittsburgh bituminous coals require a 4 to 6 in. fire. Small charges should be fired frequently.

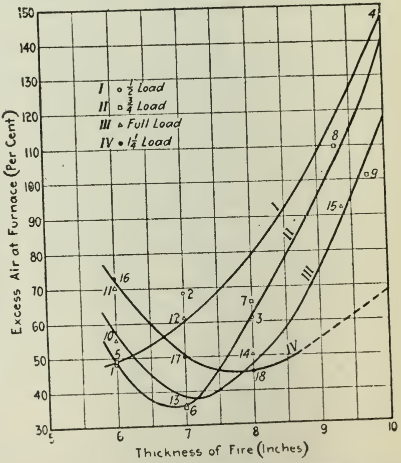
Kentucky, Tennessee, Ohio and Illinois coals require a 4 to 6 in. fuel bed.

Free-burning coals from Rock Springs, Wyoming, require an 8 in. fuel bed.

The poorer grades, such as Montana, Utah and Washington coals, require about a 4 in. fuel bed.

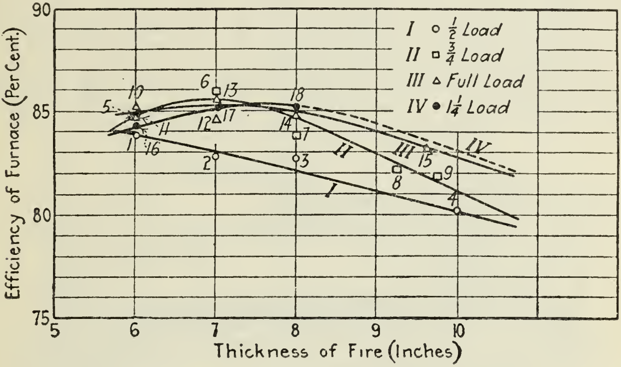
Anthracite buckwheat requires a fuel bed of 4 to 8 in.

The effects of varying the thickness of the fuel bed have been analyzed by *A. P. Kratz* in tests conducted at the University of Illinois, on a B. & W. boiler fitted with a chain grate in a Dutch oven. The combustion chamber was unusually long, being formed by a tile roof on the lower row of boiler tubes. The first gas pass was at the back of the boiler, instead of at the front. The samples of flue gas were taken from the combustion chamber just at the rear of the tile roof at the point where the gases turn to go up to the first pass. This point was so close to the furnace that no air leaks chargeable to the boiler setting could occur, and yet so far away that the combustion was complete. These results were obtained with a chain grate and probably indicate what can be expected from that type of furnace by varying the thickness of the fuel bed.



RELATION BETWEEN THICKNESS OF FIRE AND EXCESS AIR IN THE FURNACE

The adjoining curves show the relation between the thickness of the fire and the percentage of excess air, taking into account the load on the boiler. A 7 in. fire gives about the smallest percentage of excess air. It must be understood that the curves are only approximate, as a number of other factors beside thickness of fire affect the amount of excess air, such as draft conditions. At different loads the excess air decreases to a minimum and then rises to a maximum as the thickness of the fire increases. With a thin fire, there is a tendency to the formation of air-holes. As the depth of the fuel bed is increased a greater draft is required, and there is a greater infiltration of air. The combined result of increasing the depth of the fuel above 7½ in. is an increase in the excess air. Inspection of the curve shows that for a thin fire of constant depth, the excess air increases when the load or rate of combustion is increased, while for a thick fire of constant depth the reverse is true. When the load is made greater, a larger amount of air must be drawn through the fuel bed. In the case of a thin fire, holes burn through quickly with a heavy load. With a thick fire light loads would entail a very slow travel of the grate, with probability of burning through and admission of excess air at the back.



RELATION BETWEEN THICKNESS OF FIRE AND EFFICIENCY OF FURNACE

A study of the above curves shows that for each load there was a well-fixed thickness of fire that gave the best efficiency. As the load decreased this thickness became less. For 1¼ load the best fire was 8 to 8½ in. thick. For full load, the best fire was 7 to 7½ in. thick. For a ¾ load it was 6½ in. thick.

From experiments of the *Bureau of Mines*, the following general statements as to relation of thickness of fuel bed to draft can be made:

The rate of flow through a bed of constant thickness is approximately proportional to the square root of the pressure drop. As the thickness of the bed increases, the weight of air admitted decreases rapidly at first, then more and more slowly.

To put air at the same rate through double the thickness of bed requires twice the difference of pressure and twice the work on the fan. If the height of a cross-flow water-tube boiler is doubled, or if the length of the tubes of a parallel-flow boiler is doubled, and the thickness of the fuel bed is doubled, double the fan work will be required if the same weight of gas is to be carried through the boilers.

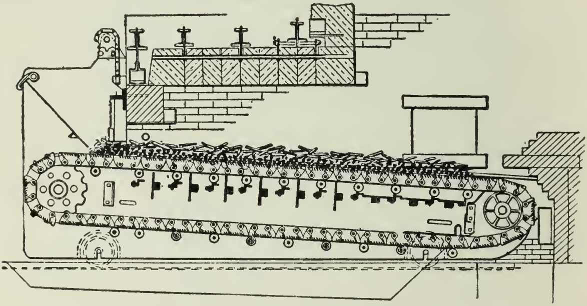
If two or three times the weight of gases are forced through a given fuel bed and boiler resistance to produce two or three times the capacity, the work expended by the fans will be 8 or 27 times as great.

MECHANICAL STOKERS AND THEIR OPERATION

The following descriptions and instructions relating to representative mechanical stokers are partly from articles by *Warren O. Rogers*. Statements by the manufacturers, regarding draft requirements for different load conditions are given on pages 129 to 132.

TRAVELING AND CHAIN GRATE STOKERS

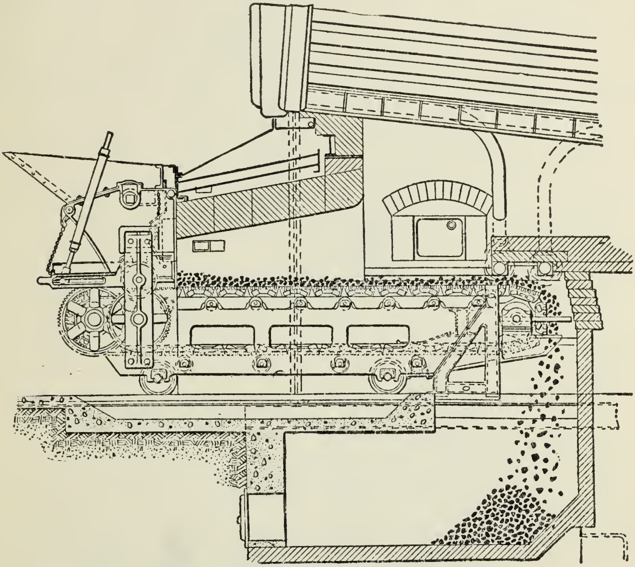
The Illinois Chain Grate Stoker is slightly inclined to the rear, and two-thirds of its active length is covered by a flat suspended combustion arch. Either forced or natural draft may be used. It is not provided with a water-back at the bridge wall. A series of hand-operated dampers just below the upper layer of the traveling links is built into the stoker, and as the load is decreased, a proportionate amount of the chain grate surface can be made inactive, and excess air prevented.



ILLINOIS CHAIN GRATE STOKER

The Playford Chain Grate uses a ventilated and air-cooled flat ignition arch extending over the grate surface at the front of the boiler. Several types of construction are used at the bridge wall for preventing clinker from adhering, and preventing the ingress and leakage of air over the grate. In some cases a four-inch diameter wrought pipe is used as a fixed water-back, and in others a special air-cooled movable back is installed. A movable water-cooled back can be used, which can be located within one inch of the grate chain. The movable feature permits holding the fuel bed on the grate until it is entirely consumed, and also permits the dumping of large clinker into the ash-pit, instead of pulling it out through the inspection door. A water-cooled fuel grate at the front prevents back-firing of the coal in the hopper. The amount of power required varies from 1½ to 1 H.P. per boiler, or from .2 to .6 of 1% of the rated capacity of the boiler, depending upon the size and number of units.

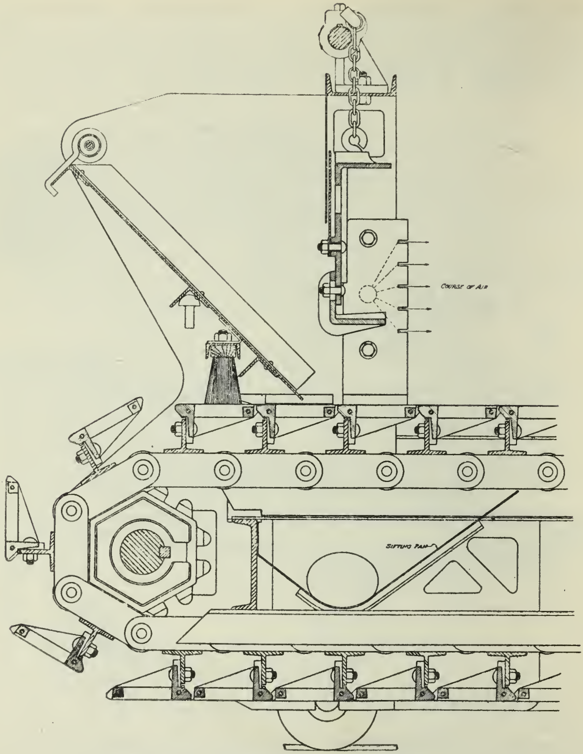
The Green Chain Grate, Type "K," is built for free-burning coals, and type "L" for coking coals. The type "K" is shown in the cut. Natural draft is used with type "K," while forced draft is used with type "L." Type "L" is provided with an inclined apron below the fuel gate, on which the coal is coked before moving out onto the chain. Adjustable flanges on the ledge plates fit against the sides of the upper chain, presenting a durable surface to the moving fuel bed, and preventing air leakage between the chain and the side walls. An igniting arch is necessary with a chain grate stoker to reflect the heat and ignite the coal as it comes from under the gate. This arch should be as flat as possible to insure uniform ignition over the whole width. The Green stoker has a specially designed ventilated flat arch suspended on tee bars. In some cases a stationary water-back is used in the bridge-wall.



GREEN CHAIN GRATE STOKER—TYPE K

The Simplex Traveling Grate.—Natural draft is usually used with this stoker. Either sprung or flat suspended ignition arches may be used. Either low or high pressure water-backs are supplied. A sheet metal covering in two sections prevents the coal in the hopper from coming in contact with the hot gates. Although the smooth action of the grate sifts only small quantities of coal through the grate, a sifting pan is provided under the front section of the grate, from which the coal is removed by a worm screw.

The Laclede-Christy Chain Grate.—It is claimed that no air enters except through the fuel bed. The fuel gate has no guides and therefore swings tight against the ignition arch, preventing leakage of air. The side frames have a slight slope toward the rear and bear against the under side of ledge tile, preventing air leakage around the sides of the stoker. These ledge tile are of a special abrasive resisting refractory. A stationary baffle between the top and bottom of the chain, suitable wing plates on the side frames closing the space to the side walls, and a rocking iron plate on the back wall of the dripping pan in the plane of the stationary baffle, prevent air leakage over the end of the stoker below the bridge wall. The lower side of the chain bears lightly on the iron plate on the dripping pan rear wall. The bridge wall overhangs the grate to the point where it breaks and rises vertically. This



SIMPLEX TRAVELING GRATE STOKER

vertical wall reflects heat under the ignition arch with beneficial results. The arch is flat and suspended from a rigid frame. A swinging damper between the upper and lower parts of the chain permits the rendering of the rear 30% of surface inactive.

The Babcock and Wilcox Chain Grate Stoker.—The side frames are cast iron, and are flush with the top surface of the chain. The inner sides are machined, offering a guide for the side links. On the outer edges are side seals, held by guide bolts which permit a vertical motion. Weighted levers against the under side of the seal plates hold them against the cast iron side plates which are built into the brick walls and overhang the side frames of the stoker. This completely excludes air at the side of the stoker. At the rear of the grate a structural channel between the top and bottom of the chain forms a part of an air baffle. Immediately below the chain in the plane of this channel is a steel plate baffle with a hinged portion extending to the bottom of the ash-pit, completely sealing the rear. A chain connected to the hinged portion is brought to the front of the stoker, by means of which a greater or less amount of air may be admitted to the rear to meet varying conditions of combustion. A water box in the bridge wall is a part of the standard equipment. It acts as an air seal, limits the thickness of the bed of consumed fuel which may pass under it, and prevents the admission of large quantities of air. This water box is connected to the circulation of the boiler.

Coxe Traveling Grate (Combustion Engineering Corporation).—There are four or more compartments below the grate. The air pressure in each is varied according to the thickness of the fire above each of them. A combustion arch usually covers ⅔ to ¾ of the grate.

Instructions for Chain Grate Operation.—Generally one operator and one coal-passer can handle about ten chain grate stokers. With chain grates either natural or forced draft can be used, although certain coals are not adapted to use forced draft successfully. Chain grates are usually large in area for the boiler, when compared with other types of stokers; the normal forcing capacity averaging 260% of boiler rating, with the combustion rate up to 48 lbs. per square foot per hour, with coal suitable for the stoker. With low ash coal, this rate of driving would probably cause the grate to become overheated, and high maintenance cost would result. To obtain best operating results, it is essential that the draft be under control, and that wide-open and tight-shut positions of the damper be determined and marked, and that dampers operate readily between these positions.

All gate leveling bolts can be adjusted to obtain a uniform fuel bed, but, before making this adjustment to correct an uneven fire, be sure that it is due to the gates and not to other causes. Some settings provide definite arch ventilation, and the openings through the side and curtain walls must be kept clear, and indicate air circulation.

If the ledge plate flanges provided in some settings have been disturbed by the settling of the brick work, they should be set to within ⅛ inch of the stoker chain, to cut off air leaks between the chain and furnace wall.

For efficient operation, no unconsumed fuel should be carried over the end of the grate, and frequent gas analyses should be made. A few days' experimenting will determine the proper relation between fuel bed thickness and speed of grate. See that all air openings around the front of the stoker are effectually closed.

If the fire tends to draw away from the gate, decrease the speed, increase the thickness of the fuel, or adjust the dampers. The thickness of the fuel bed is shown on the gate indicator. Variation in gate height is necessary with coals varying in fineness and in volatile proportions. It is better to run a thick fire slowly than thin fires rapidly. The average speed should be about 3½ inches per minute. Keep the grate covered by closing the dampers and slowing down the stoker with decreasing load, and vice versa with increasing load. Keep the bottom side of the feed gate tile in line, as an uneven fuel bed makes an uneven fire. Insert new tiles when the old ones are burned or broken down. Dampers should not be entirely closed during operation. A furnace draft of $\frac{1}{10}$ in. should be the lowest draft permitted.

If the fire tends to pass over into the ash-pit, the fuel feed is too fast or too thick, or the furnace is given insufficient draft. The fuel should be just consumed upon reaching the rear turning point. The back end of the grate should never become bare of live coals.

Adhesions usually form on the side walls. About once in 6 hr., run a bar under the hopper apron and gate, being careful not to dislodge the gate tile. This should be repeated regularly, as often as necessary to keep the side wall clean and prevent the side links from being burned.

Ashes should not be allowed to accumulate in a pile around the chain.

This may tend to overheat it, and burn it out. Neither should the drippings of coal be allowed to accumulate. Put a little back into the hopper at a time, a large amount will act to make holes in the fire. It is not a bad plan to wet the drippings. Do not stop the stoker for any length of time with the hopper full of coal, as the fire will burn forward and injure the gate. Do not run short fires with the damper wide open, as high brick-work maintenance and poor economy will result. Do not try to regulate the fire by opening the doors in the stoker setting. In washing out the boiler, be careful not to wet the stoker arch, as nothing is more injurious. Keep the arch dry. With a coking coal, it is necessary to run a slice bar through the fuel bed occasionally to break it up and permit free passage of air.

If run at proper speed, so that no unconsumed fuel runs over the end, the links at the stoker front can be touched with safety. The speed should be such that all volatile matter will have been driven off the coal by the time it has traveled not more than half the length of the grate. Varying loads can be easily taken care of by proper regulation of the thickness of the fuel bed and the speed of the grate. The damper will have to be regulated accordingly. Insufficient draft causes smoke in the stack and possibly in the feed hopper. If smoke is noticeable in the feed hopper, allow it to empty and inspect the gate shoes to determine whether they are being burned. If so, allow the hopper to remain empty until the shoes cool off.

To force the fire, open the boiler damper wide, speed up the grate, lower the feed gate, and loosen up the coal. A ¾ in. bar with a 6 in. bend at the end can be used. Run it through the furnace with the 6 in. leg flat on the grate. When at the rear, turn the bar completely over and pull it out. Continue until the whole grate has been gone over. Never disturb the top surface of the fuel bed.

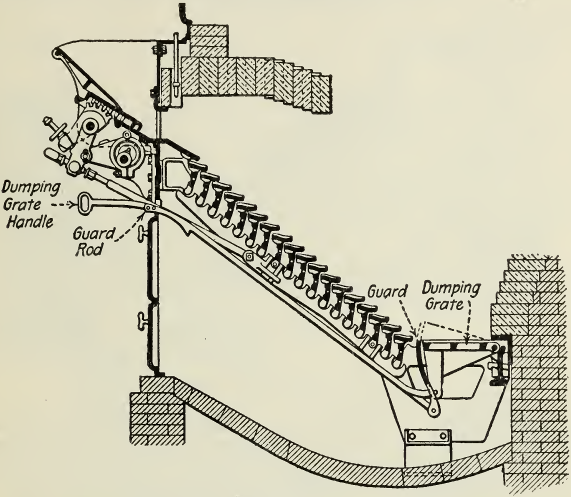
To bank the fire, let the hopper empty, stop the grate, partly close the damper, giving $\frac{1}{10}$ in. draft in the furnace, until the fire burns short. Close the damper almost to the smoking point. Loosely bank the coal against the lower edge of the gate, allowing a little air to get through. At intervals of 5 hr. run the grate ahead a little.

To bring a banked fire up to rating, stir up the fuel bed with a bar, partly open the damper, lower the gate to the operative point, fill the hopper, and as soon as the arch is thoroughly heated, start the stoker at a rate that will keep the fuel ignited at the gate. When the grate is completely covered, the damper may be opened and normal operation begun.

OVERFEED STOKERS

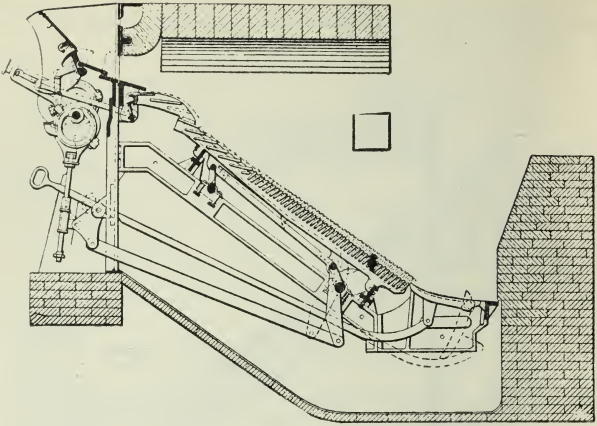
In most types of overfeed stokers, coal is pushed in at the top of a sloping grate and coked by the aid of a fire-brick arch. The coal is moved from the top to the bottom of the grate by various motions of the bars, aided by gravity. Clinker collects at the bottom, and is crushed or dumped according to the design of the stoker. Coking is confined to the top of the furnace. The packing of the green coal makes it impossible for air to get through under slight differences of pressure, and air for burning the volatile is supplied from openings in the arch, or from excess air admitted through the lower part of the grate.

The Westinghouse-Roney Stoker.—A reciprocating action of the lower plate on the front of the hopper causes the coal to slide onto the coke plate underneath an arch, which assists in the ignition. The grate bars are transverse, and rock backward and forward. Natural draft is used. For cleaning the fire, a guard is lifted into position between the dumping grate and the regular grate bars. This should break the clinker free from the grate. The ashes are dumped by tilting the dumping grates.



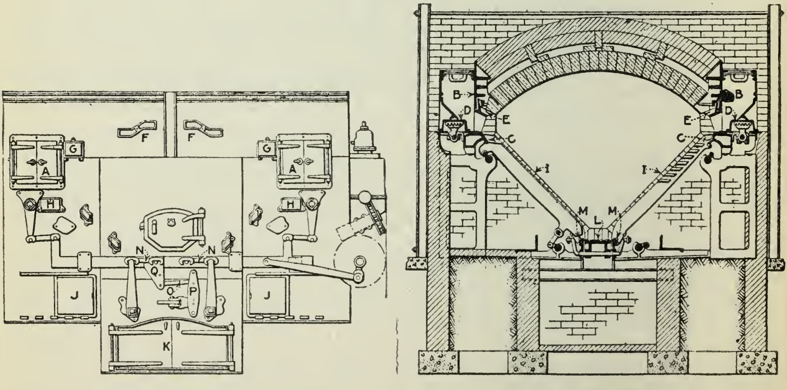
WESTINGHOUSE–RONEY OVERFEED STOKER

The Wetzel Stoker consists of three grates inclined throughout their entire length. The coal is shoveled or mechanically fed into the hopper, and a coal pusher operated by an eccentric pushes it onto the dead plate, and then onto the coking grates. The coking grates, driven by a link connection to the coal pusher, move the coal onto the main grate. The main grate consists of a series of movable bars, and a series of stationary bars, placed alternately. The movable bars are operated by a bell crank and eccentric from the main shaft. The extreme position is shown by the dotted line in the cut. This moves the fuel down the grate, and discharges the ash onto the dumping grate. When a sufficient amount has accumulated, it is dumped by throwing a lever. Air through the fuel bed is duly proportioned to the speed of combustion of the fuel. The coking grate contains an exceedingly large percentage of air spaces, the upper part of the main grate a smaller percentage, the lower part of the main grate still less, the dumping grate a very small percentage. Above the dead plate, coking grate and upper part of the main grate is sprung a fire-brick arch. A large amount of air passes through the coking grate to mix with the volatile gases. They rise into the reverberatory furnace, and are completely consumed. The upper part of the main grate admits a somewhat less amount of air for the combustion of the remaining fuel. The lower part of the main grate admits a still smaller quantity of air for the consumption of the coked fuel. The dumping grate admits a very small amount of air, to complete the combustion of the slight amount of unburned fuel. In this way, the grate is designed to supply a large quantity of air for the volatile gases, and prevents excess air coming through the part of the grate on which the ashes are located.



WETZEL OVERFEED STOKER

Murphy Automatic Furnace.—Coal is shoveled through the magazine doors *A*, or it can be delivered into the tops of the magazines through coal chutes. From the magazines *B*, the coal is pushed out on the coking plate *C* by the reciprocating pusher boxes *D*. The hydrocarbon gases released during coking mix with the heated air admitted through the tuyere openings *E*. The air supply is regulated by the dampers in the furnace front. The burning coke moves slowly down the inclined grates *I*. The air supply for combustion enters through the stoker fronts at several points. Air admitted through the dampers *F* passes between the furnace arches, becomes heated



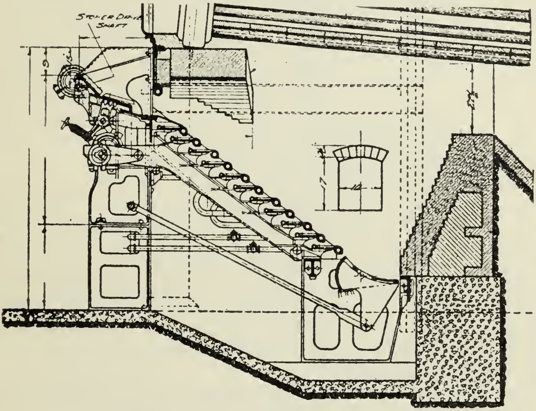
Front

Section

MURPHY AUTOMATIC FURNACE

and enters the furnace through the arch boxes. Air admitted through the upper hoods *G*, which have sliding dampers, passes through the arch boxes and out through the tuyere openings. Air admitted through the lower hoods *H* passes through the coking plates *C* and up through the rear chamber into the arch boxes and then out over the fire. Two doors *J* are for admitting air under the grates and for the removal of fine coal siftings that may fall through the grates. Doors *K* are for admitting air under the grates and for the removal of ashes.

A crusher forming the lower and center part of the furnace takes care of clinkers. The toothed shafts or the disks *L*, as the case may be, are to grind the clinkers and deposit them in the ash-pit. The exhaust pipe from the stoker engines connects with perforated pipes *M* that run below or along the upper side of the grate supports, and are so placed that the steam blows between the clinker grinders and between the grates at their lower ends. The steam is intended to soften the clinker.



COXE-FULTON OVERFEED STOKER

Coxe-Fulton Stoker.—An ordinary pusher feeds coal from a hopper onto the coking plate underneath an ignition arch. The grate bars are horizontal, cast solid, with a steel tube imbedded in the front edge. Water from the boiler circulates through them, and also through the fuel gate, keeping them cool to prevent burning out and adhering of clinker. Alternate grate bars have a motion imparted to them by the stoker engine so that they move onward, forward, upward and backward, thus causing the coal to work downward on the grate. Air enters between the grate bars. 64% of the equivalent grate surface is air opening. It is claimed that there is no sifting of fine fuel through the grate. The dump plate pivots, so that the fuel is held on the grates during dumping.

Operation of Overfeed Stokers.—Trouble may arise from fusion of ashes in contact with the side walls and bridge walls. Excessive clinkering can be prevented by slicing the fires and dumping the ashes before they fuse. If dumping periods are infrequent, the fuel will be all consumed. If dumping is done at too short intervals, the combustible is not all burned. The fireman can determine the length of time between dumpings.

Keep the grates covered with fuel, the thickness depending upon the load. The inrush of cold air through an uneven fuel bed will decrease the efficiency, and can be prevented by regulating the fuel feed.

With a **Roney Stoker,** after dumping the ash, return the dumping grate to its closed position before lowering the guard grate; otherwise large coals will drop into the ash-pit. If a clinker will not dump, break it loose and pull it out with a hook, instead of slamming the dumping grate open and and shut in the attempt to free it, as this will cause burning coal to drop off the lower part of the grate. The length of the fire can be regulated by the speed of the stoker. It should not be worked through the side inspection door, as a mass of coal will slide down the grate. Poking at the front of the grate tends to cause a mass of coal to slide down, necessitating the dumping of green coal on the upper portion of the grate. For increased steam demands, speed up the stoker. With high steam pressure, slow down the stoker, even stopping it rather than close the ash-pit doors.

The Murphy and Detroit Side-Feed Stokers are similarly operated. If possible the engine should be kept running continuously, and the grate kept in motion. If necessary to stop the engine, remove the rocker link, and see that the vibrating grates are down out of the fire, to prevent their burning.

The thickness of the fire, and the draft, are matters of experiment with a given coal. A fire about 3 to 4 inches usually gives best results. If the fire is too thick on one side of the grate, remove the pusher links for a short time. If it is too thin, remove the pusher links and with a hand-socket wrench push a sufficient amount of coal onto the grate to even up.

A bar is used through capped roust holes for breaking up the fuel bed, on sudden steam demands, and for filling holes in the fire. Under no circumstances should the grate be covered through the fire-doors, as this will reduce the efficiency of the furnace.

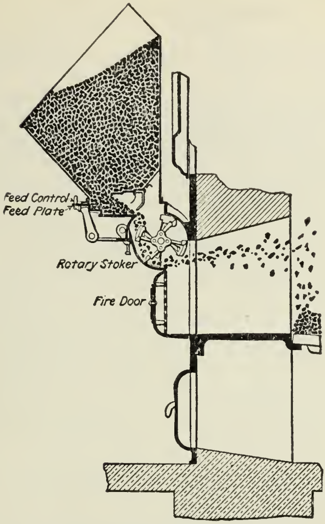
Some trouble may be experienced from clinker adhering to the crushing rolls, or the failure to crush large clinker. Barring will then be necessary. When operating at capacity, there should be no trouble from clinkers. The hand lever can be used to break up the clinker, and a few turns of the crusher will clean the fire. The proper speed of the crusher depends upon the kind of coal and its clinkering qualities.

For continuous running, the magazine should be kept full of coal. When thrown in by hand, the back end should be filled, using a hoe to push the coal back, and the coal in front left 5 or 6 inches from the top for observing the feed. The magazine should be evenly filled, to insure an even distribution of the coal on the grate. When coal is fed from overhead, the coal slides should be closed from time to time, and the magazines allowed to empty, to make sure that even feed is being obtained. When the stoker is to be shut down, gauge the supply so that the magazines will empty, and the fire burn out, otherwise the coal will have to be pulled out of the magazine doors, to prevent its catching fire.

To bank a fire, first clean it, and remove all the clinker from the stoker. Then pull the coke to the front ends of the grates. Cover the live coal with fine coal. Close the doors on the front of the stoker, and nearly close the dampers. Be sure there is no coal in the magazines.

In starting from a banked fire, spread the coke along the bottom of the grates, cover them with coal through the magazines, and open the draft doors and dampers, leaving the air flue opening *G* in front of the stoker partly closed.

To avoid burning the grates, ashes should never be allowed to fill up the ash-pit.



SWIFT THROWING STOKER

The Swift Throwing Stoker throws the coal in small amounts continuously onto all parts of the fuel bed, the rate of throwing being adjusted to the rate of burning. Fire doors permit access to the fire for observation and correction of any irregularity, due to clinker, etc. The presence of clinker is shown by dark and thick areas, on which the coal does not burn down as fast as elsewhere. Clinker must be removed by a hook and the spot patched with fresh coal placed by a shovel. Do not attempt to patch by raking live coal over the spot, as this invites another clinker at the same spot. This type of stoker carries a thin fire, which should be disturbed as little as possible.

It may be necessary from time to time to remove fine coal from the dead plate. Move part of it to the front corner of the grate, and part behind the pier between the stoker openings. Never shovel fine material to the center of the fire.

The stoker should not be started until the fire bed is level, admitting air uniformly. The equipment will then maintain the bed in a level condition. With rocking or dumping grates, do not operate so violently that the fire and ashes mix. This invites clinker, and lets patches of fire through the grate. When increasing the feed, to take care of large loads, give the feed control screw one turn at a time, and wait two or three minutes before giving it another. Increasing the feed at intervals in this way allows time for the furnace to change its combustion rate without producing smoke. It is also easy to determine when the rate is sufficient.

Screenings, when extremely dry, should be moistened but not soaked. If the coal is wet, the hopper should be observed occasionally, to see that the coal is not hanging and preventing regular feeding.

Fires are started, cleaned and banked in practically the same manner as in ordinary hand-firing.

UNDERFEED STOKERS

Jones Stoker.—Coal from the hopper is pushed forward and upward by the intermittent action of a ram and pusher block. The fire is always on top. Fresh coal is slowly pushed upward, gradually heated and coked. The volatile driven off during the coking process mixes with the air from tuyere openings in the sides of the fuel trough before reaching the incandescent zone of the furnace. Forced draft is used. Air is blown through a duct into a sealed ash-pit which supplies the tuyeres, the supply being controlled by a blast gate in the duct. An engine-driven forced draft fan in combination with the stoker is controlled by an automatic control apparatus consisting of a sensitive pressure controlled valve in the steam line to the blower engine. If the steam pressure drops, the regulating valve acts to increase the speed of the engine, causing a corresponding increase in the air and fuel supply. An increased steam pressure causes an opposite action. The automatic control valve is equipped with a pointer, the location of which indicates the rate of feed. The control valve can be hand-operated in emergencies.

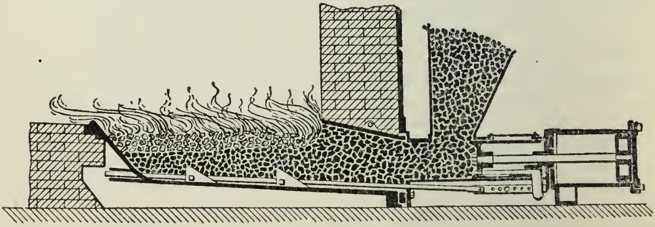
The coal supply should be continuous, and sufficient to maintain a heavy fire from 14 to 24 inches deep over the retort. The index figures on the control valve can be used to control the fuel supply. Never shovel coal on top. To build up the fire or to cut it down, the valve may be hand-operated.

Fires must be cleaned when the accumulation of non-combustible interferes with combustion. The greater portion of refuse forms in a clinker on the dead-plate. Lift the clinker from the dead-plate with a slice bar, turning it over to shake off the live coals, and remove the clinker with a hook. Never expose the dead-plates to the intensity of the fire, but leave ash and unconsumed coke on them. The retort will clean itself. Always shut off the draft and do not let the fire burn too thin before cleaning.

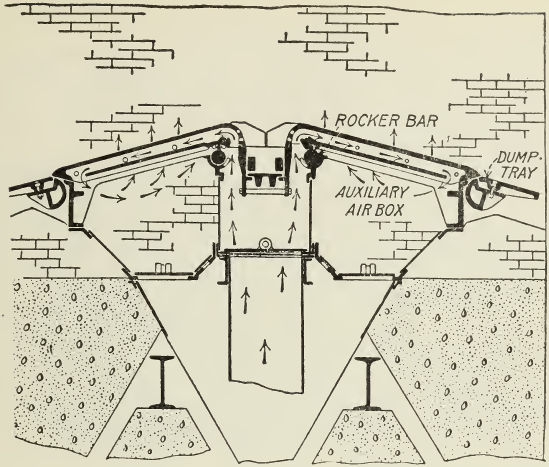
A proper stroke of the pusher rod will maintain a constant depth of fire throughout the length of the retort. A short stroke will increase the delivery of coal to the front of the stoker.

To bank the fires, introduce several charges of coal by means of the ram, shut off the draft, and close fire doors and damper. If banked for long periods, clinker and coke may form in the retort. Clinker should be removed and the coke broken up before the ram is again operated.

When the stack draft is insufficient, some gas is likely to pass out through the hopper. This may also be occasioned by allowing the fire to burn too deep in the retort, or by allowing clinker to remain immediately over the front of the retort. Smoke coming back through the retort may also be caused by too lumpy coal.



JONES UNDERFEED STOKER



COMBUSTION ENGINEERING CO. TYPE "E" UNDERFEED STOKER

Type "E" Stoker of the Combustion Engineering Corporation uses a central wind box and a ventilated grate. Coal is fed into a hopper on the outside of the furnace and is delivered by gravity to the front end of the bottom of the retort. It is pushed into the furnace by a steam-driven feeder-block until the retort is filled. Auxiliary pushers raise the coal onto the grate bars. Alternate grate bars reciprocate with the pusher, spreading the coked fuel toward the dump trays. The movement of the grate bars conveys clinker and ashes to the dump trays. There is consequently no need to clean the grate bars. The slight inclination of the grates is not sufficient to cause gravity travel of the coal.

After the original adjustment, no hand adjustment is necessary. Automatics are furnished to take care of the load. Controlled by these each stoker can have an individual drive and be independent of every other stoker. A stoker may be cut out of service and held with banked fire while the load is light ready to be cut in. By feeding additional coal occasionally, the fire may be kept in a banked condition several days. To start up, dump the ashes, open the air gate, and then start the stoker. It is imperative that the fireman realize that the fire should not be sliced or poked, the stoker takes care of breaking up the fuel. When the load is light, if too many boilers are used, the fire carried will be too light. This is wasteful, as the fire should be uniform in thickness, with no holes.

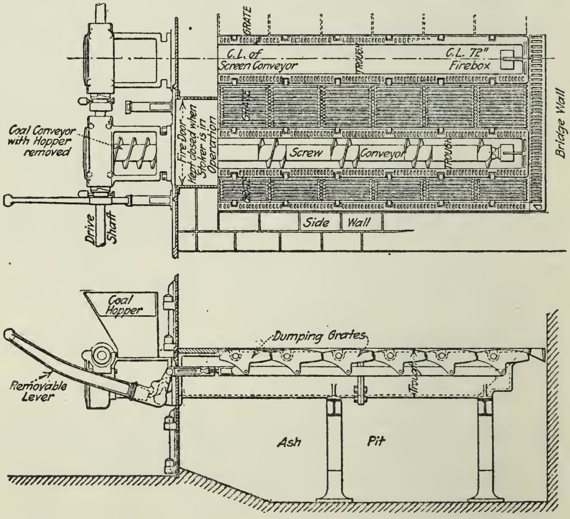
Probably the most important point to consider in the operation of an underfeed stoker is the proper supply of coal and air. These should be carefully studied. When determined, the automatic should be adjusted, and permitted to maintain the proper proportions. The relation of available draft to the amount of coal must be studied. The coal crusher is designed to feed from 7½ to 8 lbs. of coal per stroke, and as the strokes may be adjusted from none to 8 per min. it is a simple matter to supply the proper amount. Generally 2 in. draft will supply enough air to take care of 4 strokes per min. or feeding 32 lbs. of coal, so that all the carbon is burned out by the time the coal reaches the dump plates.

Automatic regulation of coal and air is obtained by means of a damper regulator sensitive to slight variations of steam pressure, acting on a balanced throttle valve on the blower engine or motor rheostat. Variation in feeding the coal is obtained by a chain connection between the regulator and the valve controlling the stoker.

Care should be exercised to see that live coal does not accumulate on the dump plate. This tends to raise the temperature, and consequent fusing of the refuse into a solid clinker, making dumping hard, and a consequent loss of coal in the ash. If perchance, large clinker forms on the dump plates with carbon intermixed, close the ash-pit doors and open up the grids in the air box, putting the dump trays under forced draft. At the same time, stop the stoker until the combustible in the fuel along the dumps is at least partly consumed. The grids should be closed again as soon as possible. The dumps should be eased out a trifle, to prevent growing into the side walls as the draft strikes them and makes the fire excessively hot at that point. If this condition is not frequent, the brickwork will not be injured. In an emergency, when for any reason excessive rating is required for short periods, it may be obtained in this way. This is seldom necessary, as 300% rating can be carried continuously, and higher ratings for short periods.

A 10 to 12-in. fire is usual. The stack should be large enough to take off the products of combustion. It is folly to attempt to carry more fire than the stack draft will take care of, as the furnace and fronts will become overheated, and the brickwork and front will be high in upkeep. Always keep the fire as near incandescent as possible.

The frequency of dumping depends upon the coal. Generally it should



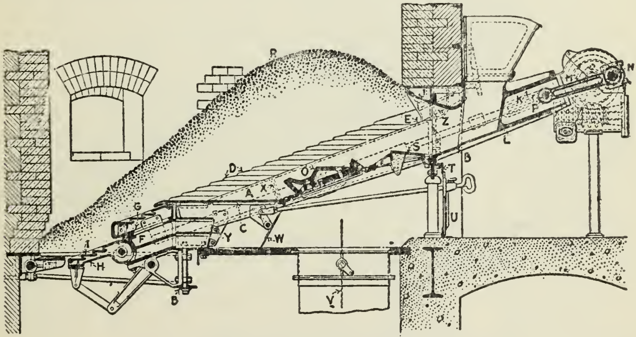
STEVENS UNDERFEED STOKER

be at least every 2 hrs. Fires should be kept clean. When, with a low fire, it is found that for any reason unburned coal is on the dump plate, it should be winged back with a bar. The saving is worth while.

To bank the fire, run the stoker very slowly. Leave full draft on until the fire is well burned down. Stop the stoker, and continue burning down until all the fuel on the grates is burned out. Shut off the air, dump the ashes, and clean the ashes from the fire box. Start the stoker, and feed in enough coal for the required duration of the bank, after which close the boiler damper and ash-pit doors.

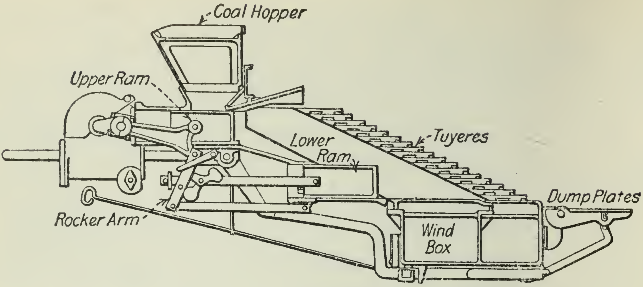
The Stevens Stoker is a combination of intermittent coal feed screws and rocking grate. Either natural draft or a steam blower is used. The intermittent screws distribute the coal evenly over the entire area. The coal hoppers are removable, and hand firing can be carried on should the stoker become deranged. The fires can be cleaned similarly to hand-fired grates. Banking is also similar.

The Moloch Stoker is an underfeed type, with horizontal retort, into which coal is fed by a ram and pusher. The tuyeres are placed at the upper edge of the retort. Several retorts are placed under one boiler, the distance apart being determined by a rotary clinker crusher, which grinds the refuse and deposits it in the ash-pit. For small installations, the clinker crusher is replaced by a manually-cleaned refuse plate.



WESTINGHOUSE UNDERFEED STOKER

Gravity Underfeed Stokers are used very extensively, especially in the East, and include the Taylor, the Riley and the Westinghouse, which are similar in many respects. They are underfeed, in that the green fuel is fed beneath the burning fuel, which rests on a sloping grate. The gravity feature is found in that the fuel bed is inclined, and the refuse moves automatically out of the ignition zone as soon as the carbon is consumed. Coal is fed by a plunger from the hopper into the fuel magazine or retort, from which it is pushed out into the coking zone of the furnace, a second plunger or pusher performing the latter office in the Westinghouse and Taylor. Below the coking zone are extension grates. In the Riley stoker the retort sides, called side bars, and the overfeed or extension grates have a reciprocating motion. Several retorts are placed under each boiler. The space between them forms an air chamber, the top of which is composed of tuyere blocks. Air is supplied by a forced draft fan, carried to the tuyere boxes by suitable



TAYLOR UNDERFEED STOKER

ducts, and forced through the tuyeres into the fuel bed. Each design has individual dumping plate features.

Operation of Gravity Underfeed Stokers.—In starting, be specially careful not to get too heavy or too hot a fire on the ash plate. With some kinds of coal, it may be necessary to put the ashes at the lower end of the stoker, to prevent burning the ash plate. Be always sure that there is very little burning coal on them. In case it is necessary to get the fire out of the furnace quickly, the best method is to close the air blast, leaving the stack damper open, open the dump plates, and deaden the fire with water from a hose, then push it into the ash-pit, where it may be extinguished. Under no circumstances should the water be allowed to touch the brickwork.

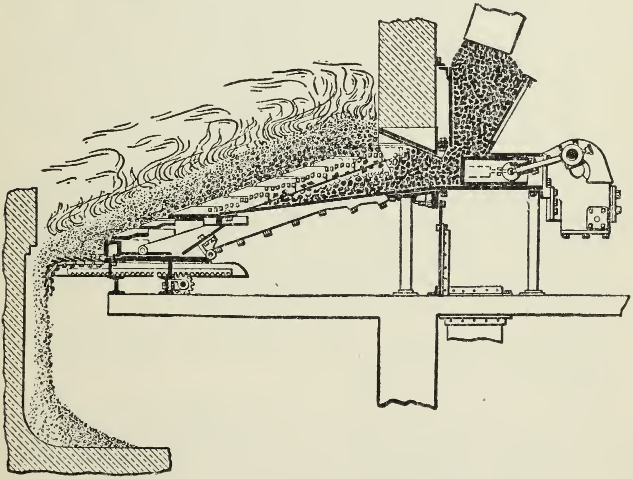
Do not keep the ash discharge open any wider than necessary to allow the ashes to fall through. It is best to keep it closed enough to maintain a bridge of ashes over the opening, and a thick bed of ashes on the ash plates to protect them. If it is necessary to dump hot refuse, be sure to quench the fire in the ash-pit. In case of large clinkers that will not dump, it will be necessary to withdraw the ash-support plate temporarily to let the clinkers through. With the Riley Stoker, if the clinkers stick to the bridge wall, do not use the bar, but change the travel of the pusher nose opposite the clinker. Give it the maximum travel of about 5 in. just long enough to break up the clinker. One or two strokes may do it. If run too long at this stroke, too much green coal will be fed down.

To bank the fires, shut off the air entirely, and push in coal until the required depth of bank is obtained, depending upon the length of time the stoker is required to stand. Do not use much travel, if any, on the side bars, when banking fires. In banking fires, do not let them burn down to the tuyere plates or air box, which would be injured. If the air box becomes badly cracked, it will allow fuel to get into it, which will burn and further injure the metal.

In starting from banked fires, turn on the air and start the side bars at their minimum travel. If the fuel bed is heavy, run the stoker with the hopper empty, without feeding fuel until the side bars have broken up the bed, and it has had a chance to burn to normal thickness.

With a new fire in a Riley stoker, the dump plate should be set with not more than one or two inch space from its end to the bridge wall. After operating for an hour, or more, depending on the rate of running and the grade of coal, the ash plate should be opened about one section, depending on the conditions of fuel at the back of the fire. After a period of two hours, open the same amount and repeat after another interval of the same length. By putting an extra stroke adjuster on the side bars, the tail end of the fire will be brought down into the ash-pit. The time interval may have to be varied. The principle is that as a fire gets older, it also gets dirtier, hence a gradual opening of the ash plates with a corresponding discharge will keep a practically clean fire. There should then be no piling of hot fuel near the bridge wall to cause clinker. The side bars should always have at least one stroke adjustment, to obtain ideal cleaning conditions. Clinkers sometimes adhere to the side walls. Although stokers are automatic in the cleaning process, there are coals that form such clinker that it is desirable to resort to a bar with a chisel point to be driven between the clinker over the tuyere plates. Care should be exercised not to injure the side walls. Under some conditions a slice bar for cleaning the soft clinkers and for breaking up the fire can be used to advantage.

Shearing pins are provided, so that if the ram becomes clogged, these will let go without serious damage to the stoker. It requires but a few minutes to replace them.



RILEY UNDERFEED STOKER

FURNACE TEMPERATURE

Hays says that: "As a general proposition, the higher the furnace temperature the greater the efficiency." Higher CO_2 and the absence of CO result in higher initial furnace temperature.

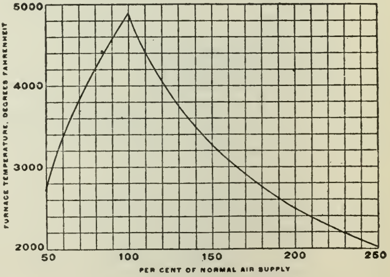
As discussed under the section on "Air Theoretically Required," the rapidity with which combustion takes place is greater at higher temperatures. That is, at the higher temperature, the combustion of the gases is more nearly complete in the time allowed for passage through the furnace.

Extreme temperatures are destructive of brick work, but high temperatures will not burn boiler tubes or sheets, provided they are clean, that is, free from deposits of scale, sludge, oil, etc., and the boiler circulation is such that water is kept in contact with the metal.

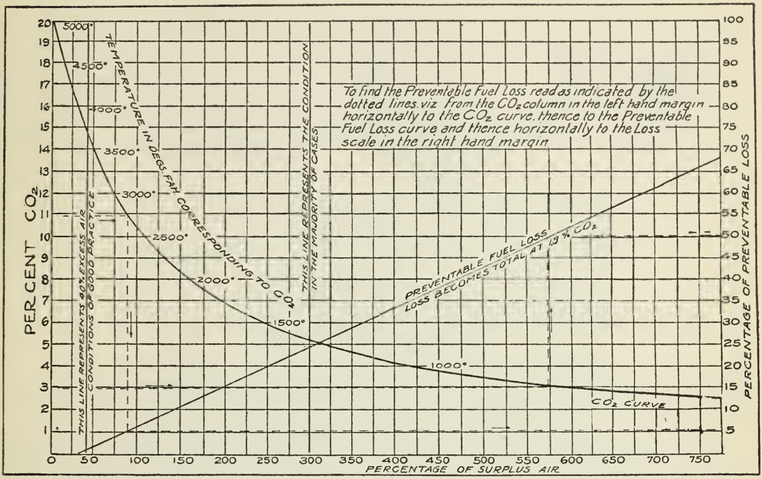
The *Bureau of Mines* says that: As long as combustible gases are kept at a temperature sufficiently high to allow of their combustion, the advantages to be gained by a further elevation of their temperature are partly, if not entirely, offset by resulting disadvantages. In one instance, the arch was removed so that there was direct radiation from the fuel bed to the shell. The lower furnace temperature resulted in less clinker formation. It also gave a slower distillation of the volatile gases, and therefore better smoke consumption. High temperature at the rear of the combustion chamber may be due to low air supply, high rate of combustion, or to the nature of the coal. Reducing the air supply will generally increase the efficiency. High temperature at this point due to high rate of combustion or to the nature of the fuel is usually accompanied by low efficiency. Although the rate of burning coal and the air supply may be equivalent, the coal with the higher volatile combustible will show the higher temperature at the rear of the combustion chamber. High temperature at the rear of the combustion chamber is therefore not a positive assurance of high efficiency. It may indicate that the point of intense combustion of gases is near the tubes and that there is a loss due to incomplete combustion. The gases then enter and leave the tubes at higher temperature and more heat is wasted in the stack.

Chart on page 101, by *Hays*, shows that with an increase in the percentage of CO_2, the furnace temperature rises. This chart also shows the relation between percentage CO_2 in the flue gas and per cent. excess air. Cutting down the excess air produces higher furnace temperature, which may result in a higher flue gas temperature. Building up the CO_2 percentage may apparently increase the heat loss up the stack if the flue gas temperature alone is considered, but the actual quantity of heat going up the stack is decreased, for the quantity of gases has been decreased.

The small chart adjoining, also by *Hays*, shows the relation of furnace temperature to the per cent. of normal air supply.



RELATION BETWEEN PER CENT. AIR SUPPLY AND COMBUSTION TEMPERATURE



To find the Preventable Fuel Loss read as indicated by the dotted lines. viz from the CO_2 column in the left hand margin horizontally to the CO_2 curve, thence to the Preventable Fuel Loss curve and thence horizontally to the Loss scale in the right hand margin

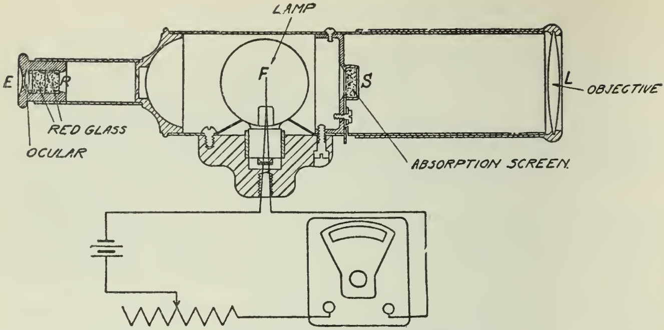
RELATIONS BETWEEN CO_2, THEORETICAL FURNACE TEMPERATURE, EXCESS AIR AND FUEL LOSS

Pyrometry.—*White & Taylor* give the following table of the temperatures corresponding to different colors of light emitted from the furnace:

Character of Light	Temperatures, Deg., F.
Dark red, blood red, low red	1050
Dark cherry red	1175
Cherry red	1375
Bright cherry, light red	1550
Orange	1650
Light orange	1725
Yellow	1825
Light yellow	1975
White	2200

There are practical difficulties in the use of thermocouples for measuring high temperatures. The *Bureau of Mines* found that couples of platinum and platinum-rhodium were not satisfactory for boiler furnaces. The insulating tubes were cracked or otherwise destroyed by slagging action. Bare-wire couples were destroyed by the gases.

Optical pyrometers can be used for obtaining the temperature of the furnace and the combustion chamber, provided it is not necessary to look through flame or smoke. The *Leeds & Northrup* Optical Pyrometer is based on the principle that the intensity of light from incandescent bodies varies in a definite manner with the temperature. Light from the incandescent body is compared with a standard source. The eye is very sensitive in judging which is the brighter of two areas, especially when one is small and superimposed on the other. The two areas can be made of equal brightness, either by varying the amount of light admitted from the incandescent object, or by varying the intensity of the standard. The latter method is preferred



OPTICAL PYROMETER

by the *U. S. Bureau of Standards*, and is applied in this pyrometer, which is shown above.

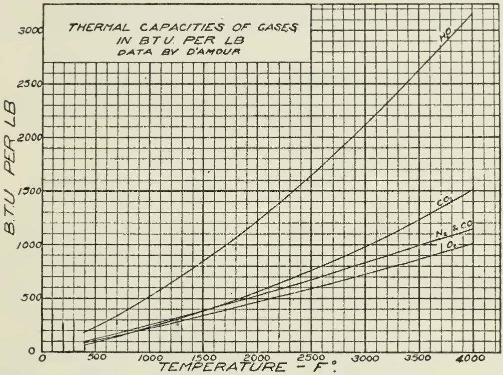
L is a lens through which radiation from the incandescent body whose temperature is to be measured is brought to a focus at the point *F*. A tungsten lamp filament is placed at *F* in the plane of the image. This filament receives current from a small storage battery contained in a portable case, together with a rheostat and an accurate milliammeter. The incandescent filament and the image produced by the lens are observed through the eye-piece *E*. The current through the lamp is adjusted by the hand rheostat until the brightness of the filament is just equal to the brightness of the image, upon which the filament becomes indistinguishable. The adjustment can be made with great accuracy, for the effect of radiation upon the eye varies 15 to 20 times faster than the temperature. The milliammeter can be provided with a scale to read in degrees of temperature, or the temperature can be obtained from a calibration curve supplied with the instrument. The red glass placed in the eye-piece overcomes the dazzling effect, and eliminates any question of matching colors. For temperatures above 2500° F., the light received through the lens would be blinding. The instrument is therefore fitted with a screen which can be turned into place for reducing the light admitted from the hot body.

A large surface to sight at is not required, and distance makes no difference. All bodies when enclosed within a furnace of the same temperature emit "black body" radiation, and their temperatures can be read directly. The same is true of some bodies, such as carbon, in the open, also approximately of iron and steel in the solid state. For bodies which glisten, as molten metals, a correction factor must be used, if they are viewed in the open.

The *Wanner* optical pyrometer has been used by the *Bureau of Mines*. It is a photometer. The standard light is a 6-volt incandescent lamp illuminating a ground glass surface and energized by a three-cell storage battery. A beam of monochromatic (red) light from this source is produced by a direct-vision spectroscope and a screen cutting out all but a narrow band of red. This and a similar band from the hot body are passed into a photometric telescope, each beam illuminating one-half of the field. The comparison is made by adjusting both halves by means of a polarizing arrangement. The lamp is standardized by means of an amyl-acetate standard lamp.

TEMPERATURE OF COMBUSTION

The following charts, adapted from *D'Amour*, can be used to determine the maximum possible furnace temperature from the ultimate analysis of the coal and the analysis of the furnace gases; if the furnace gas analysis is not available, it can be assumed the same as the flue gas. The curve below shows the total thermal capacities of the principal gases in B. T. U. per pound of gas at various temperatures, thus taking into account variations of specific heat with temperature.



THERMAL CAPACITIES OF FLUE GAS CONSTITUENTS

The method of using this chart is best explained by a practical example. Assume, as a furnace gas analysis, $CO_2 = 11\%$, $O_2 = 0.3\%$, $CO = 0.2\%$, $N_2 = 88.5\%$, obtained by burning a coal of the following analysis:

Carbon	82.88%
Hydrogen	4.13%
Oxygen	2.61%
Nitrogen	1.38%
Sulphur	1.51%
Ash	7.49%

Heat value, 14,659 B. T. U. per lb.

As may be computed, the excess air is 77.5%.

A furnace temperature curve is plotted as follows for the composite flue gases resulting from the combustion of a pound of the given coal. The proportion by volume multiplied by the molecular weight of each constituent gas gives its relative weight. The relative weight divided by the sum of all the relative weights is the proportion by weight, as shown in the following table:

Gas	% by Volume	Mol. Wt.	Rel. Wt.	% by Wt.
CO_2	11.0	44	4.84	16.25
O_2	.3	32	.096	.32
CO	.2	28	.056	.18
N_2	88.5	28	24.78	83.30

Taking five temperatures, say, 4000, 3000, 2500, 2000 and 1000° F., the thermal capacities of the different gases at these temperatures are picked from the thermal capacity curve and multiplied by the proportional weights.

The sum of the products thus obtained is the thermal capacity per pound of the composite furnace gas. The product of the thermal capacity per pound of gas by the number of pounds of gas per pound of coal gives a point on the furnace temperature curve.

The weight of gases per pound of coal is found as follows:

$$\text{Lb. air supplied per lb. coal} = 3.036P\left(\frac{N_2}{CO_2 + CO}\right)$$

P = carbon burned, stated as proportion of the coal.

= proportion of carbon in coal minus proportion of carbon which is in ash.

N_2 = proportion by volume of nitrogen in the flue gases.

Assume 5% of coal went into ash-pit, and that 25% of this was carbon. Then .05 × .25 = 1.25% of coal is carbon in ash.

P = 82.88 — 1.25 = 81.63%.

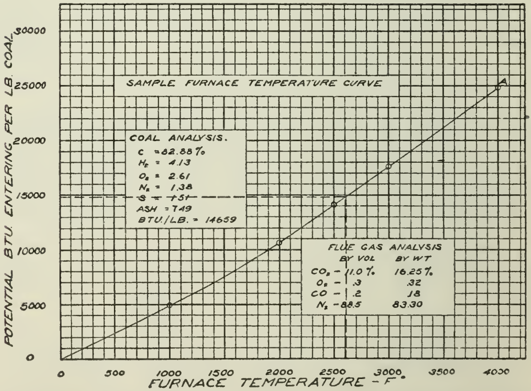
$$\text{lb. air per lb. coal} = 3.036 \times .8163 \left(\frac{.885}{.112}\right) = 19.57$$

95% of coal is present in gases.

Therefore pounds of gas per pound of coal = 19.57 + .95 = 20.52 lb.

The total heat of the gases of combustion per pound of coal, at 4000° F., say, is then found as follows:

Gas	Proportion by Wt.	Thermal Capacity Per lb., from curve of capacities at 4000° F.	Total thermal capacities
O_2	.0032	1010	3.23
CO	.0018	1150	2.07
N_2	.833	1150	957.95
CO_2	.1625	1515	246.18
Total thermal capacity per lb. gas =			1209.43 B.T.U.



FURNACE TEMPERATURE CURVE FOR COAL AS GIVEN

Total heat in gases per lb. of coal = 20.52 × 1209.43 = 24,817 B. T. U., which is point *A* on the furnace temperature curve on page 104. The heat capacities of the gases of combustion at 3000, 2500, 2000 and 1000° F. are calculated similarly.

The heat entering the furnace per pound of coal actually burned, is the heat value of the coal, plus the sensible heat in the air used to burn a pound of coal. Assume the air temperature as 70° F.

Heat in air = 19.57 × (70 — 32) × .24 (.24 is the specific heat of air) = 178 B. T. U.

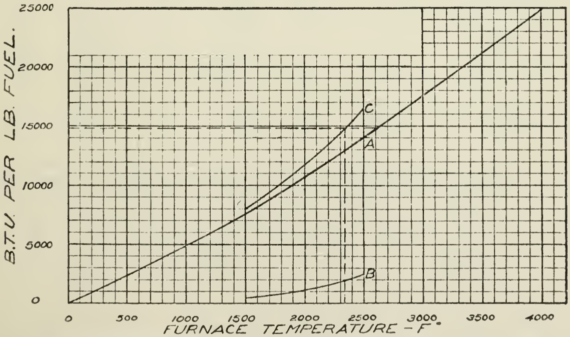
The temperature in a furnace where the fuel bed radiates to the heating surface of the boiler can be estimated by combining a radiation curve with the above curve of heat capacity of the gases. As stated by *Deinlein*, when equilibrium is established, the heat corresponding to the reduction of the combustion temperature is equal to the heat radiated by the fire bed at the reduced temperature. Therefore

$$Gc\,(t_1 - t_2) = C\left[\left(\frac{t_2 + 460}{1000}\right)^4 - \left(\frac{t_3 + 460}{1000}\right)^4\right]\phi\, R$$

G = weight of gases.
t_1 = the combustion temperature without radiation.
t_2 = the true fire temperature.
t_3 = the temperature of the heating surface receiving radiation.
c = specific heat of the gas.
C = radiation constant.
R = combustion surface.
ϕ = coefficient giving the fraction of the heat radiated from the grate which falls on the heating surface (see section on Radiation, page 194).

For example, assume grate surface R = 50 sq. ft., combustion rate = 25 lb. per hr. per sq. ft., boiler pressure = 175 lb. per sq. in., corresponding temperature of boiler heating surface = 375° F., C = 1600, and ϕ = 50%. The calculation of this fraction of the radiated heat which falls on the heating surface is complicated by the presence of the side walls. The value assumed is probably the upper limit for most practical installations.

At a furnace temperature of 2000°, the B. T. U. radiated per hour (by formula) = 1,440,000. There are 1250 lb. of coal burned per hour, so the



COMBINED RADIATION AND HEAT CAPACITY CURVE heat radiated is 1150 B. T. U. per lb. This gives a point in the radiation curve. Repeat for two or three other temperatures and plot curve, as shown on page 105. Curve *A* is the combustion temperature without radiation, from page 104; curve *B* is the radiation curve and *C* is the sum of the two. The horizontal dash line represents the total heat entering the furnace per pound of coal. Its intersection with curve *C* gives the furnace temperature as 2330° F., as against 2605° F. without radiation.

Total potential heat entering furnace per pound coal = 14659 + 178.
= 14837 B. T. U.

The resulting furnace temperature as found from the coal curve is 2610° F., assuming that there is no loss of heat from the fuel bed by radiation, but that all of the heat is carried in the gases of combustion.

See discussion of radiation error under flue gas temperature, page 140.

FURNACE GASES

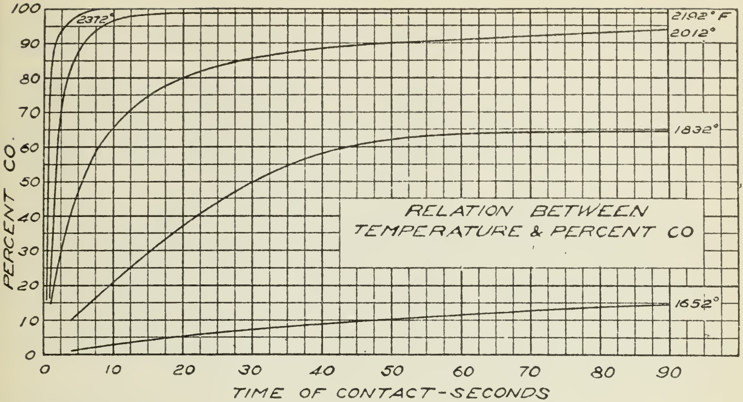
When a fresh charge of bituminous coal is first spread over a hot fuel bed, the coal is heated up rapidly, and part of the combustible is distilled off shortly after the coal reaches the fuel bed. This distillation is a cooling process, and tends to hold the temperature down. The distilled volatile combustible is carried into the combustion space, where it is more or less completely burned, thereby raising the temperature.

The combustible which is distilled during the first two or three minutes after firing is in the form of gas and tar vapors. The latter burn relatively slowly, and if not consumed in the furnace are condensed by the cooling action of the boiler to liquid or semi-liquid globules of tarry substances, which form a part of the black smoke at the top of the stack. Only a small quantity escapes unburned when there is a reasonable amount of combustion space. The table below shows the composition of the furnace gases leaving the fuel bed for three minutes immediately after a firing, as given in a *Bureau of Mines* report.

TEST ON COLLINSVILLE, ILL., NUT COAL

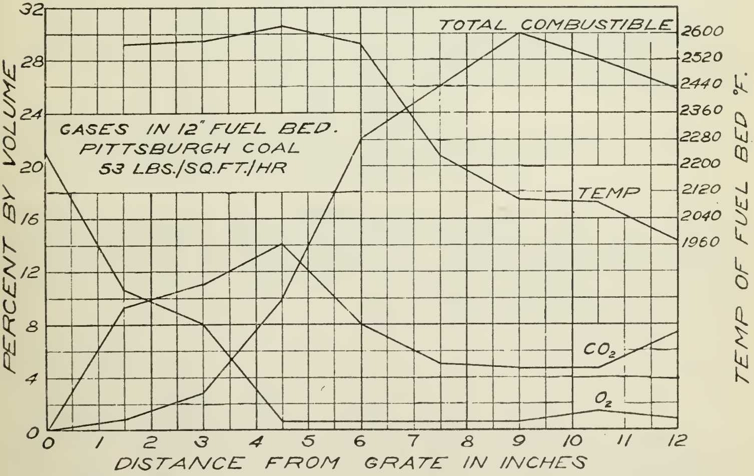
	Per cent. by volume						
Time during which sample was taken	CO_2	O_2	CO	C_nH_m	H_2	CH_4	Total combustible
First Half Minute....	7.6	2.3	18.3	.2	1.0	1.2	20.7
Second Half Minute..	6.9	1.0	19.8	.3	3.6	1.4	25.1
Third Half Minute...	4.7	.7	20.1	.4	5.5	2.6	28.6
					5.8	2.5	28.8
Fourth Half Minute..	4.8	2.2	17.4	.4	4.2	4.5	26.5
					5.0	4.3	27.1
Fifth Half Minute ...	5.9	1.4	19.1	.2	7.6	3.0	29.9
Sixth Half Minute ...	6.6	1.6	15.8	.0	6.8	4.1	26.7

The hydrogen and methane are low immediately after firing, and gradually increase, while the illuminating hydrocarbons reach a maximum about two minutes after firing, and decrease to zero at the end of the third minute. The carbon monoxide remains high during the entire period of three minutes, while the percentage of carbon dioxide is comparatively low. The high carbon monoxide is partly the product of distillation of volatile matter, and partly the result of decomposition of carbon dioxide. In the lower layer of the fuel bed the carbon burns with oxygen to CO_2. As this passes through the upper layer of hot coke or coal, a molecule of carbon dioxide takes up an additional atom of carbon, and is reduced to two molecules of CO.



RELATION BETWEEN TIME OF CONTACT AND PER CENT. OF CO IN THE MIXTURE OF CO AND CO_2 WHEN CO_2 HAS BEEN PASSED THROUGH INCANDESCENT FUEL AT DIFFERENT TEMPERATURES

The percentage of CO formed when CO_2 is in contact with hot carbon depends upon the temperature of the carbon and CO_2, and to a certain measure on the length of time of contact. The above chart shows the relations.



COMPOSITION OF THE GASES AND TEMPERATURES AT DIFFERENT DEPTHS OF A FUEL BED 12 IN. THICK OF PITTSBURGH COAL BURNED AT THE RATE OF 53 LB. PER SQ. FT. PER HR. IN A SMALL HAND-FIRED EXPERIMENTAL FURNACE.

In this connection it may be said that water vapor passed through incandescent carbon at 1112° F. will result in CO_2 and H_2; at 1832° F., CO and H_2 will form.

Inasmuch as the temperature of the fuel bed in a boiler furnace is generally above 2400° F., the gases leaving the fuel bed are apt to be high in CO and low in CO_2, even though the bed may be only a few inches thick. The boiler furnace is a fairly good gas producer. From gas analyses the conclusion is reached that the gases leaving the fuel bed are rich in combustibles and low in free oxygen. See the chart on page 107.

The low percentage of CO_2 leaving the fuel bed indicates that the fuel bed acts as a gas producer. It changes the solid fuel to gas, to which additional air must be supplied and the mixture burned in the combustion space. These facts prove the importance of spacious combustion chambers. For this reason some provision to supply air above the fuel bed is made in most of the commercial appliances designed to burn soft coal. Furnaces for soft coal generally have large combustion spaces. Gas-mixing structures are still in the experimental stage, their chief drawback being the lack of durability under the high temperature which fuel economy requires:

ANALYSES OF GASES FROM TOP OF FUEL BED AND REAR OF COMBUSTION CHAMBER IN A HEINE BOILER SETTING WITH PLAIN GRATES, 6.2 CU. FT. COMBUSTION SPACE PER SQ. FT. GRATE, AND GAS MIXING ARCH, BURNING TENNESSEE COAL

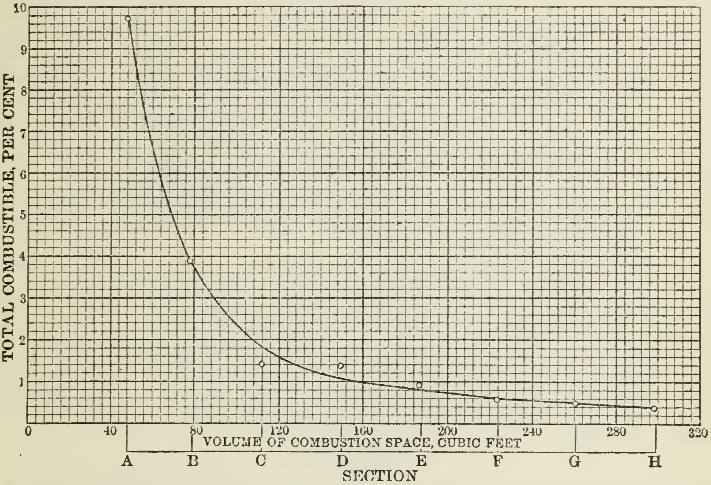
	Time	CO_2	O_2	CO	H_2	CH_4	C_nH_m
Test No. 364, 21.90 lbs. of dry coal per sq. ft. grate per hr.							
Top of fuel bed	12.30	5.7	0	20.3	6.0	2.7	0
Rear of comb. cham	12.30	12.6	5.6	0	...	...	..
Test No. 367, 26.41 lbs. of dry coal per sq. ft. grate per hr.							
Top of fuel bed (a)	7.30	4.4	7.4	9.5	1.2	2.4	.8
Rear of comb. cham (b)	7.30	13.3	0	.9	...	...	..
(a)	9.30	5.4	0	23.6	7.8	1.2	.2
(b)	9.30	15.5	.6	.7	...	...	..
(a)	11.30	5.2	.2	23.8	5.4	1.8	0
(b)	11.30	14.6	.2	1.0	...	...	..

The above table shows that the combustible gas is nearly completely burned by the time the gases reach the rear of the combustion chamber. The gases can easily be burned. It is the tar vapor and the small solid particles of floating carbon that present the difficulty in the combustion of soft coal.

COMBUSTION SPACE IN TYPICAL ACTUAL BOILER SETTINGS

Type	Grate surface sq. ft.	Comb. space cu. ft.	Comb. space with 12-in. fire	Ratio comb. space to grate area	Ratio comb. space 12-in. fire to grate area	Rate of comb. lbs. coal per sq. ft. grate surface	Sec. each cu. ft. stays in comb. space
(*a*) Normand	58.6	136	78	2.34	1.33	40	.077
(*a*) Locomotive	30	160	130	5.34	4.33	60	.17
(*a*) Heine	35	250	215	7.14	6.14	25	.58
(*b*) B. & W.	87.4	318	230.6	3.64	2.64	42	.15
(*b*) B. & W.	87.4	318	230.6	3.64	2.64	13	.49

The effect of increasing the volume of the combustion space is shown by a series of tests conducted by the *Bureau of Mines* at Pittsburgh. The larger the combustion space the more effective is the mixing, and therefore the combustion is more complete and smoke is less liable to be found. Curve below shows the completeness of combustion at different points in a large combustion chamber. At a point where the gases from a Murphy Stoker of 25 sq. ft. projected grate area had passed through 160 cu. ft., there was 1% of combustible in the gases. After they had traversed 250 cu. ft., there was ½% of combustible in the gases.



RELATION BETWEEN COMBUSTIBLE CONTENT OF FURNACE GAS AND VOLUME OF COMBUSTION SPACE WITH AN AVERAGE RATE OF FIRING OF 65.4 LB. OF COAL PER SQ. FT. PER HR. ON A MURPHY STOKER

CLINKER

The subject of ash fusing temperature, which determines the clinkering tendencies of a coal, is treated on page 38. The *Bureau of Mines* names the following as usual causes of clinker trouble: thick fire, excessive stirring of the fire, burning coal in the ash-pit, much slack in the coal, closed ash-pit doors and the preheating of air admitted under the grates. Any coal will clinker if the ash is heated to the fusing temperature. Ash in an oxidizing atmosphere, as near the bottom of the fuel bed, has a higher melting point than in a reducing atmosphere, as near the top of the fuel bed. The difference is as much as 260° F.

A thick fuel bed causes clinker trouble as often as all other causes put together. A thick fuel bed cuts down the air supply and permits the ash to become heated. Air in passing through the grates and the fuel bed absorbs heat from the grate bars and the ash upon them, thus keeping them relatively cool. The fusing temperature of the ash is lowered by the reducing atmosphere in the upper layer of the ash. In a thick bed the ash mixes with the burning coal to a greater height, and the reducing zone is nearer the grate, due to the lower velocity of the air. In a thin fire the reducing zone is confined to the top inch or two of the fuel bed, where bits of ash are few and far apart, and cannot fuse together.

The second greatest cause of clinker trouble is stirring of the fire. If a caking coal is fired in large amounts it fuses. Breaking up the crust with a bar brings the ash to the upper part of the fuel bed into the reducing atmosphere, where it fuses more readily and produces clinker. Careless leveling of the fire with the rake may produce the same result. Burning coal may be shaken through the grate when leveling the fire or when attempting to fill up the holes with fresh coal. This overheats the grate bars and the ash, and clinker is very liable to result.

A large quantity of slack tends to fuse, cutting down the air. The result is the same as a thick fire, the grates and layer of coal are overheated. Closed ash doors and preheating the air have an effect similar to the above and the grates and ash are overheated. With coals forming large pieces of clinker it is always a question whether more heat is not lost by frequent cleaning of the fire than by the bad condition of the fuel bed on account of its clinker. Overall efficiency drops with increase in ash percentage. High ash reduces the capacity of the boiler by reducing the rate of combustion, and also by the fact that during the time of removing the clinker combustion is almost entirely suspended.

The following general suggestions are given to aid in overcoming clinker trouble: If possible find and remove the cause. Use thin fires; keep the fire bed level by placing the fuel on the thin spots. Avoid leveling with the rake. Above all, omit the slice bar. Fire small charges, thereby reducing the crust formation and the need of breaking it up. Especial care should be taken to do this if the coal contains much slack. Avoid burning coal in the ash-pit. If the pit is tight, keep water in it, otherwise blow in steam. The decomposition of the steam will absorb heat from the grates and the ash. Keep the ash-pit door open. Use the damper to regulate the draft.

DRAFT

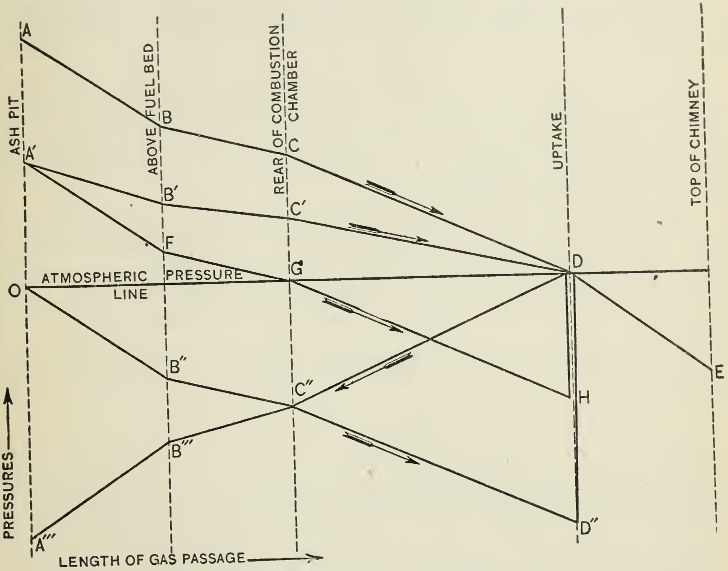
The word draft is sometimes used to signify the flow of the gases, but ordinarily it means a depression of pressure. With the ash-pit doors open and the furnace doors closed, a draft gauge connected above the fuel bed will indicate a certain reading. When the ash-pit doors are closed, the draft gauge will show an increased draft, but the movement of gases will be decreased, because the air supply has been cut off, the total resistance of the system having been very much increased. If the furnace door is opened, air will rush in with considerable velocity, but the draft pressure will have been very much decreased.

With a natural draft, the reduction of pressure at the base of the chimney is explained by the fact that the column of gases in the stack is lighter than a column of air of equal dimensions outside. The hotter the gases and the higher the stack the greater the difference of pressure.

Induced draft is produced by an exhaust fan placed between the boiler and the stack. The fan causes a reduction of pressure at the fan inlet and the atmospheric pressure in the ash-pit pushes the air through the fire, and the gases through the boiler. With forced draft, the ash-pit is put under a pressure greater than atmospheric pressure.

Balanced draft may be defined as a condition where the overpressure in the ash-pit is just sufficient to overcome the resistance through the fire, and the damper is so regulated that the depression of pressure in the up-take due to chimney or induced draft fan will just draw the products of combustion through the boiler, approximate atmospheric pressure being maintained in the firebox, thus eliminating air leakage into the latter.

The pressure relations with several kinds of draft are shown very clearly in the chart below, due to the *Bureau of Mines.*



PRESSURE DROP THROUGH A HYPOTHETICAL BOILER EQUIPMENT

The arrows represent directions of flow of gases. Line ABCDE represents pressure drops through the equipment when a fan is used to raise the pressure in the ash pit. Line A′B′C′DE represents the pressure drops through the equipment with the same fan running so as to give only half the pressure. Line OB″C″D″DE represents the pressure drop through the equipment when an exhaust fan is used to reduce the pressure in the uptake by an amount equal to D″D, the ash pit being open to the atmosphere. Line A′FGHDE represents the pressure drop through the equipment when both pressure and exhaust fans are used, but run with half the respective pressure effects of the first and third cases above. Line A‴B‴C″D represents what would be the pressure drop through the equipment if the exhaust fan of the third case above were connected to the ash pit and the uptake opened to the atmospheric pressure.

The following statements discussing the relations between the pressure drop through the fuel bed, the drop through the boiler, and the total drop, also the relations between pressure drops and resistances, are according to the *Bureau of Mines.*

If all of the resistances to the flow of gases remain constant, the pressure drop through any portion of the path will have a constant ratio to the total drop from the ash-pit to the up-take. The pressure drop through the fuel bed, considered in connection with the drop from the firebox to the uptake, indicates the fuel bed resistance.

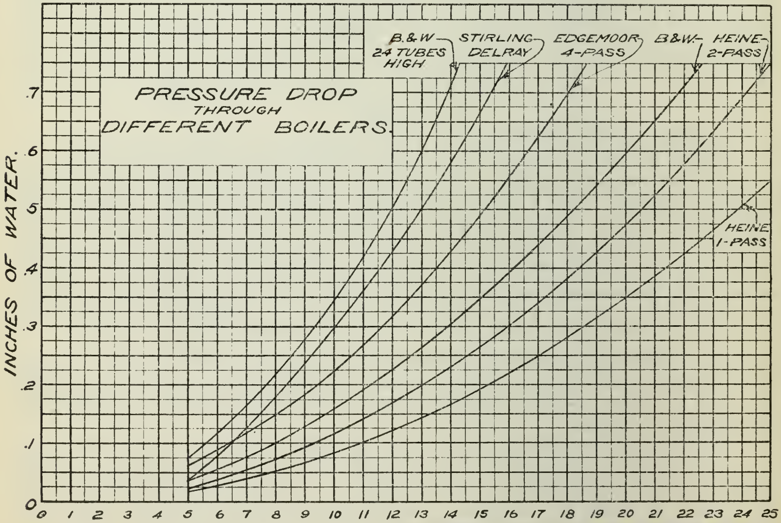
If the pressure drop from the ash-pit to the up-take remains constant, the pressure drop through any portion of the path will vary in the same direction as does the resistance to the flow in that portion, although the magnitude may not be in simple proportion. With the total pressure drop constant, more gas will flow through the boiler as the pressure drop through the fuel bed decreases. Boiler room men ordinarily expect the contrary.

When the resistance through any portion of the path remains constant, the weight of gas passing through that portion varies as some function of the pressure drop through that portion. For example, the weight of gases passing through a boiler is directly proportional to the square root of the drop of pressure.

Since the resistance of the fuel bed is ordinarily the only changeable resistance in a boiler draft problem, it may be said that the weight of gases varies inversely as the resistance of the fuel bed, the total pressure drop remaining constant. Less heat is delivered to the boiler when the resistance through the fuel bed increases, the initial temperature of the gas and the total pressure remaining constant.

High resistance may be caused by too thick fuel bed; air spaces in the grate filled with slag or air spaces too small for the coal used; dirty flues and tubes. Draft may be reduced by doors open in the setting, flues, chimney base or air duct; damper stuck or not opening far enough, due to stretch in the cable; nozzles of the steam jet clogged with baked soot, etc., or the air intake for the jets partly closed; and lastly by the chimney and flue being overloaded.

In the following sections each portion of the gas passage in a boiler installation is considered alone, and all are coordinated in the section on stack proportions.

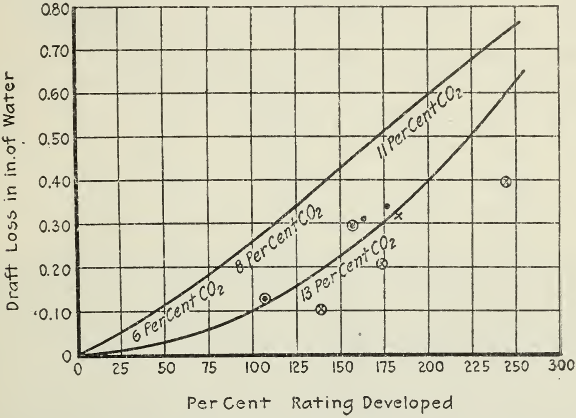


DROP OF PRESSURE THROUGH DIFFERENT BOILERS

DRAFT REQUIRED BY BOILERS

Draft loss in boilers depends upon the type and baffling, and increases with the load. According to *Steam*, approximate figures are .25 inch with boilers run at rating, .40 inch at 150% rating, and .70 inch at 200% rating.

The pressure drops through different boilers are indicated on the chart on page 112, due to *P. A. Bancel*. For rating consider about 10 to 15 cu. ft. air per min. per 10 sq. ft. of surface, depending on excess air.



DRAFT LOSS FROM FURNACE TO DAMPER OF A CROSS-BAFFLED THREE-PASS EDGEMOOR WATER-TUBE BOILER WITH 18-FOOT TUBES, FOR EFFICIENT AND INEFFICIENT FIRING

The above chart, by *A. L. Menzin*, for an Edgemoor boiler, is fairly representative of the draft required by boilers. The lower curve is applicable to boilers 15 tubes high without superheaters. The points in circles are for boilers 14 tubes high, with superheaters over the first and second passes. The circumscribed crosses are for boilers 13 tubes high, also with superheaters.

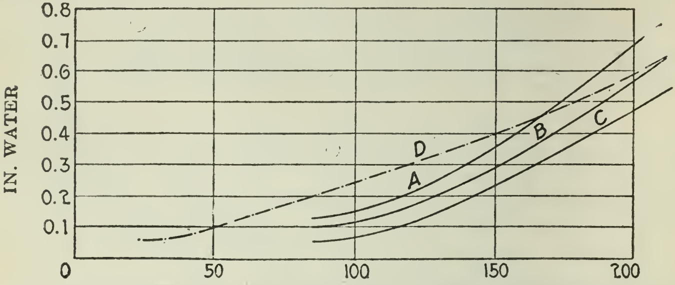
The upper curve was constructed from the lower by allowing for decreased air, but at a decreasing rate for increasing overload. While it is not unusual for a boiler to develop its rated capacity with 8% CO_2, it is hardly to be expected that a boiler will develop 175% of rating with less than 11% CO_2. The upper curve is representative for ordinary firing under favorable conditions, while the lower is for good firing. The upper curve should be used ordinarily.

The first chart on page 114, by *Orrok*, shows the draft for B. & W. boilers in comparison with an Edgemoor boiler.

DRAFT REQUIRED BY THE FUEL BED

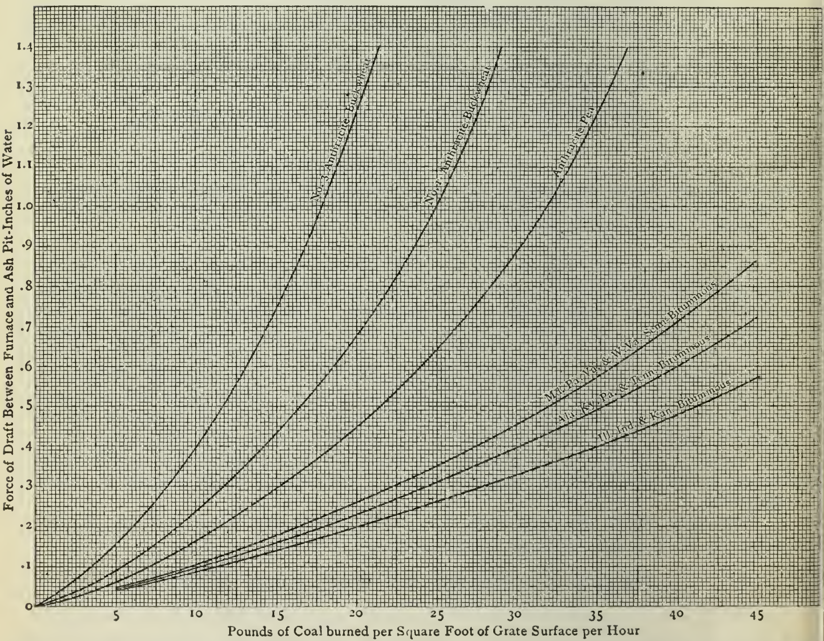
Draft loss through the fuel bed depends upon the kind of fuel, the depth of fire, the method of firing and the rate of combustion. The rate of combustion is the number of pounds of coal burned per square foot of grate surface per hour. Thickness of fire, per cent. ash and air space in the grate also are factors. Only experiment can show their effects.

The chart below, from *Steam*, shows the draft to be used with different coals for different rates of combustion with hand firing. Charts on page 115 are for chain grates.



DRAFT RESISTANCE, B. & W. BOILERS, AT ZERO TO 200% OF RATING

Measured in inches of water at third pass; A for 604 hp., B for 524 hp., and C for 260 hp. boilers, oil burning; D for cross-baffled three-pass Edgemoor boiler with coal.



DRAFT REQUIRED AT DIFFERENT COMBUSTION RATES FOR VARIOUS COALS.—*Stea*

Thickness of fuel bed assumed: Semi-bituminous, such as Pocahontas, New River, 10 to 14 inches; Bituminous, such as Pittsburgh, 4 to 6 inches; Kentucky, Tennessee, Ohio and Illinois, 4 to 6 inches; Wyoming, 6 to 8 inches; Montana, Utah and Washington, 4 inches.

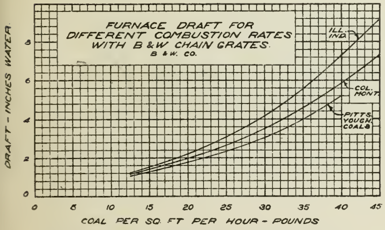
The rate of combustion required can be computed by the following formula from *Menzin:*

$$C = \frac{(\text{h. p.}) \times 33480}{UEG}$$

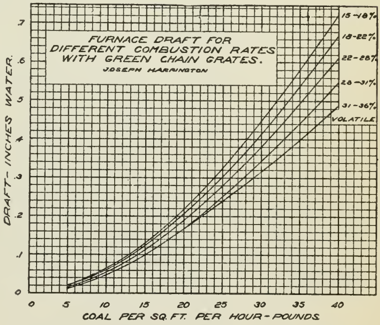
C = Maximum weight of coal to be burned in lb. per sq. ft. per hr.
H. P. = Maximum horsepower to be developed.
U = Calorific value of the coal in B. T. U. per lb.
E = The efficiency of the combined generator, and
G = The grate surface in sq. ft.

The following table of pressure difference in inches of water required to burn various coals on hand-fired grates is due to *T. F. J. Maguire:*

Rate of combustion per sq. ft. per hr.	Eastern Bit. Slack	Western Bit. Slack	Semi-Bit. Run of mine	Anthracite Pea	Anthracite Buckwheat	
					No. 1	No. 2
10	.06	.07	.07	.15	.20	.39
15	.10	.13	.12	.27	.41	.77
20	.15	.19	.19	.43	.69	1.26
25	.21	.26	.28	.63	1.05	1.90
30	.27	.35	.38	.86	1.50	
35	.35	.44	.49	1.12		
40	.42	.54	.62			
45	.51	.66	.72			
50	.61	.78	.93			



DROP OF PRESSURE THROUGH
B. & W. CHAIN GRATE



DROP OF PRESSURE THROUGH
GREEN CHAIN GRATES

FLUE PROPORTIONS

Flues should be designed with reference to the total volume of furnace gases which they are to handle, rather than according to the grate area.

The friction loss of draft in conduits (stacks, flues and breechings) can be computed by the following formula or the chart on page 124 can be used.

$$d = \frac{sW^2PHT}{A^3},$$

d = draft loss in. water column,
W = weight of gases lbs. per sec.,

P = perimeter of conduit, ft.,
H = length of conduit, ft.,
s = a factor, with the following values at sea level:
.00000138 for circular steel conduit,
.00000187 for brick or brick-lined conduit,
A = cross sectional area of conduit, sq. ft.,
T = absolute temperature of gases, degrees F.

The breeching should be of such a size that the velocity of gas flow will not exceed 35 ft per second. Experience has shown that a circular section gives less draft loss than a square or rectangular section. The retarding effect of a square flue is 12% greater than that of a circular one of equal area. The retarding effect of a 1 x 1½ rectangular flue is 15% greater. (See also page 119).

The loss of draft in bends can be calculated from the following formula:

$$d_1 = b\frac{W^2T}{A_1^2}$$

where d_1 = draft loss in. water column,
A_1 = cross section of flue, sq. ft.,
W = lbs. per sec. of gases,
T = absolute temperature of gases, degrees F.,
b = coefficient depending on bend.
b = .0000803 for right angle sharp bend
.0000219 sharp 135° angle (*i. e.*, deflection of 45°)
.0000182 right angle bend, radius equal diameter of pipe
.0000110 " " " " " 2 to 4 diams. of pipe
.0000051 " " " " " 5 to 6 diams. of pipe
0 " " " " more than 6 diams. of pipe
.0000110 135° Y branch
$.000073\left(\frac{A_1}{A_2} - 1\right)^2$ for sudden changes in cross section
A_1 = cross section of large pipe
A_2 = cross section of small pipe.

Menzin says one sharp right angle bend has the same friction as 50 ft. of length.

The draft required by an economizer can be determined from the following:

$$d_e = \left(\frac{6.606}{10^{12}}\right) F^2L\ T$$

wherein d_e = draft in. water col.,
F = flow of gases in lb. per hr. divided by the number of lineal ft. of pipe in each economizer section,
L = number of economizer sections,
T = mean absolute temperature of the gases, ° F.

The relation between draft expressed in feet head of gas (H), the volume of flow (S) in cu. ft. per sec., and the resistance (R) of the conduit is

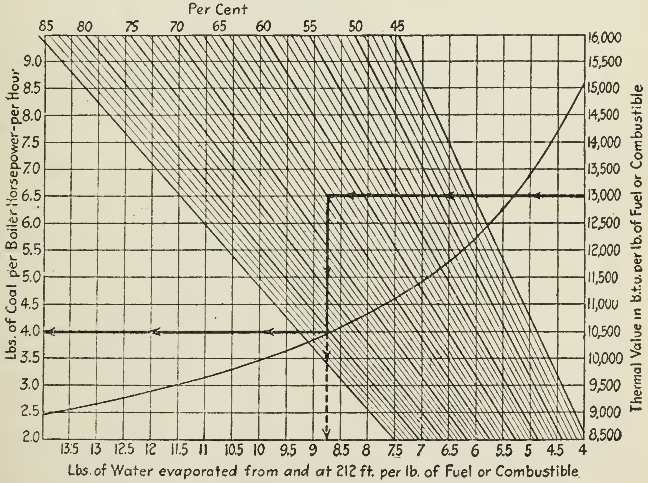
$$H = RS^2$$

R is the resistance through which 1 ft. head will force 1 cu. ft. per sec. and is the resistance of a circular orifice of .498 ft. diameter (.189 sq. ft. area) in a thin plate. A stream moving with the velocity due to H, and passing 1 cu. ft. per sec. would occupy a cross section of only .653 x .189 sq. ft., in other words the coefficient of a thin-plate circular orifice is .653. An orifice with a raised edge or collar on the up-stream side has a coefficient of about .5, if the collar is on the discharge side the coefficient is about .83, while if the entrance to the end of a suction pipe (as of a fan) is bell mounted, the coefficient is nearly unity, that is, the only head required to create flow into such a pipe is that corresponding to the velocity in the full section of the pipe; there is no entrance loss. The resistance of similar orifices varies as $1\ A^2$, where A is the area of the orifice. The resistance of a circuit containing resistances in series, as of fire bed, boiler, flues and chimney, is the sum of the individual resistances. The resistance of a circuit containing several resistances in parallel, as of a number of boiler settings discharging into a common smoke flue, is found from the equation

$$\frac{1}{\sqrt{R}} = \frac{1}{\sqrt{R_1}} + \frac{1}{\sqrt{R_2}} + \text{etc.}$$

Where R is the resistance of the circuit as a whole, and R_1, R_2, etc., are the resistances of the individual parts arranged in parallel.

W. C. Stripe gives a graphical method of determining areas of gas passages. The variable factors to be considered are boiler H.P. developed, lb. coal per boiler H.P. hr., lb. air theoretically required per lb. coal, % of theoretical air actually used, temperature and velocity of gases at the point considered. The use of the charts can best be illustrated by an example.



POUNDS OF COAL PER BOILER HORSEPOWER FOR DIFFERENT HEAT VALUES AND EFFICIENCIES, FOR FIXING GAS PASSAGE AREA

Assume 1500 boiler H.P., coal of 13,000 BTU. heating value, combined boiler and furnace efficiency 65%, air supply 175% of the theoretical, temperature of the gases at the point to be considered 1000° F., velocity of gases 35 ft. per sec. The first curve determines the coal per boiler H.P. hr. Follow the 13,000 BTU. horizontal until it intersects the 65% efficiency diagonal, drop vertically to the curved line, follow horizontally tc the left hand scale, 4 lb. of coal is required per boiler H.P. hr. Incidentally the equivalent evaporation can be determined as indicated. On the second chart, locate 1500 H.P. on scale A, project vertically to the 4 lb. coal oblique line, horizontally to the left to the 13,000 BTU. diagonal line, downward to 100% diagonal, horizontally to the left to the 175% diagonal, vertically downward to the 1000° diagonal, then to the right to 35 ft. per sec. velocity, and vertically upward to the scale F, where 30 sq. ft. is determined as the approximate effective area for the particular gas passage.

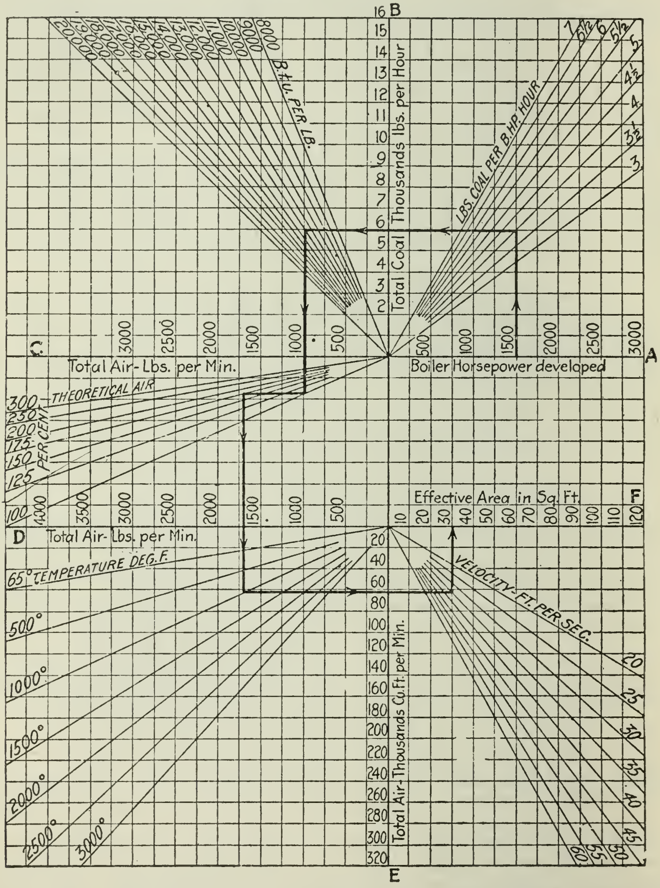


CHART FOR DETERMINING THE EFFECTIVE AREA OF GAS PASSAGES

Partial results may be obtained from any of the intermediate scales B, C, D and E.

Osborne Monnett made the following recommendations to the Standards Committee of the Smoke Prevention Association:

Breechings should be as short and direct as possible, preferably having a direct run, without turns, into the stack. No right-angle turns should be used. If turns are necessary, they should be long-sweep bends with a radius on the center of the turn of not less than the diameter or width of the breeching. The breeching should not dip below the horizontal, but should slope upward to the stack. The connection to the stack should preferably be at an angle of 45°. Breechings should not be constructed of brick or other porous material subject to leakage. Breechings of steel plate should have reinforcing angle irons on the outside, and no projections on the inside to resist the flow of the gases. Lagging should be on the outside, where its condition can readily be inspected, where repairs can be made without interrupting the operation of the plant and where loose pieces will not obstruct the flow of the gases. Clean-out doors should be provided at convenient points for the removal of accumulations of soot.

For water-tube boilers the area of the breeching should not be less than 22% of the total area of the grate surface served, or a ratio of breeching to grate surface of 1 to 4½. For horizontal return-tubular boilers the area of the breeching should be 25% in excess of the total area through the tubes. Breechings should preferably have a circular or square section. In case of rectangular shape, one side should not be more than one-third greater than the other.

Steam recommends that flue areas should preferably be 20% larger than the stack. A safe rule is to allow 35 sq. ft. for 1000 H.P. Proportion the areas of different parts of the flue to the volume of gases to pass through it. For circular steel flues of about the same size as stack, or flues reduced proportionately to the volume of gases, a convenient rule is to allow .1 in. draft loss for 100 ft., and .05 in. loss for each right-angle turn. This holds good for square and rectangular flues. For brick or concrete flues, double the figures.

STACK PROPORTIONS

The proper height and diameter of a stack depend upon

1. The amount of fuel to be burned,
2. Its nature,
3. The temperature of the gases,
4. The grate area,
5. The design of the flues,
6. The arrangement of the flues relatively to the boilers,
7. The altitude of the plant.

The amount of fuel to be burned determines the quantity of gases, while the temperature and altitude determine the volume of this quantity of gases. 1, 3 and 7 must therefore be considered in determining the diameter.

The amount of fuel, its nature, the grate area and the design of flues and gas passages determine the draft intensity required. The stack height and the gas temperature determine the draft intensity available.

A method for proportioning stacks on a gas basis is described by *A. L. Menzin:* The draft available at the boiler damper must be sufficient to give the gases velocity head (P_v), overcome the fuel bed loss (P_g) and the boiler loss (P_b). It is also the theoretical draft produced by the stack (P_z) less the friction loss in the stack (P_c), less the friction loss in the breeching (P_r) and the damper friction (P_d). Expressed as a formula:

$$P_g + P_b + P_v = [(P_z - P_c) - P_r] - P_d \qquad (1.)$$

P_g = draft through the fuel bed
P_b = draft through the boiler
P_v = draft required to produce velocity
P_z = theoretical draft produced by the stack
P_c = friction draft loss in the stack
P_r = friction draft loss in the breeching
P_d = friction draft loss at damper, which can be considered zero for a well-designed damper wide open.

Since the proportions of oxidizable matter per lb. of different fuels varies between very wide limits, the minimum amount of air required per lb. of fuel for complete combustion varies accordingly. The air per lb. of combustible is less variable. The air per BTU. is almost constant. For several samples of lignite, bituminous and semi-bituminous coals, anthracite and California crude oil, the calculated minimum moisture-free air per 10,000 BTU. by the bomb calorimeter did not vary more than 1½% from 7½ lb. The BTU. basis is therefore adopted for determining the quantity of gases equivalent to a given boiler H.P.

The draft through the fuel bed (P_g) can be determined, as on page 115. If forced draft is used for the fuel bed, as in stoker installations, the stack does not have to take care of this item.

The draft through the boiler (P_b) can be estimated, as on page 112. *Menzin* uses the curve on page 113, as sufficiently accurate, since condition of equipment must be assumed.

The draft to produce velocity, (P_v),

$$= .123 \frac{P\,(v_2^2 - v_1^2)}{30\,T}$$

P = barometric pressure,
v_1 = initial velocity of gases in ft. per sec.,
v_2 = final velocity of gases in ft. per sec.,
T = temperature of gases F° abs.

This is usually small. v_1 is zero, since the air is practically stationary in the ash-pit. v_2 can be assumed as in table on page 122.

The sum of these three, P_g, P_b and P_v, is the draft required at the damper.

The weight of gas per H.P. is approximately:—

$$W = \frac{33{,}480\ w}{10000\,(E + .02)}$$

W = weight of gas in lbs. per hr. per boiler horsepower,
w = weight of gas per 10,000 BTU., (may be taken from table on page 121),
E = combined efficiency of the steam generator expressed as a fraction,

.02 is added to E as an average for carbon in the ash. E and the corresponding % of CO_2 must be assumed low enough to take care of unusually poor operating.

The volume of gas per H.P. is approximately:—

$$q = \frac{30W\ T_c}{41.3\ P \times 3600} = \frac{6.73W\ T_c}{1{,}000{,}000} \times \frac{30}{P}$$

q = volume of gas in cu. ft. per sec. per boiler horsepower.
W = weight of gas in lb. per hr. per boiler horsepower.
P = barometric pressure in inches of mercury.
T_c = temperature of the gases in degrees Fahr. absolute.

WEIGHT OF GASES AND PERCENTAGE OF HEAT REJECTED TO THE CHIMNEY FOR DIFFERENT PERCENTAGES OF CO_2 WHEN $CO = 0$

Percent CO_2 in the Dry Gases by Volume	18.7	18.0	17.0	16.0	15.0	14.0	13.0	12.0	11.0	10.0	9.0	8.0	7.0	6.0	5.0
Excess air in percent of the theoretical minimum....	0	4	10	17	24	33	43	54	68	85	105	130	162	206	267
Weight of gases per 10,000 B.t.u. in the coal, lb.....	7.8	8.1	8.6	9.1	9.6	10.3	11.0	11.9	12.9	14.2	15.7	17.6	20.0	23.3	27.8
Chimney loss per 100 deg. Fahr. in percent of the calorific value of the coal.	1.85	1.92	2.04	2.16	2.28	2.44	2.61	2.82	3.06	3.37	3.72	4.17	4.74	5.52	6.59
Chimney loss per 500 deg. Fahr..................	9.25	9.60	10.20	10.80	11.40	12.20	13.05	14.10	15.30	16.85	18.60	20.85	23.70	27.60	32.95

In ordinary problems the table below can be used instead of computing the weight or volume of gases. (See also chart on page 122.)

WEIGHT AND VOLUME OF GAS PER BOILER H.P. AT SEA LEVEL

Assumed CO_2 percent of dry gases by volume	8	8	9	10	12	12	14	14
Assumed combined efficiency of boiler, grate and furnace............................	63	66	66	68	70	75	68	78
Weight of gases in lb. per hr. per boiler H.P..	91	87	77	68	55	52	49	43
Volume of gases in cu. ft. per sec. per boiler H.P. for a temperature of 540° F. and 30 in. of mercury............................	.61	.58	.52	.46	.37	.35	.33	.29
Suggested corresponding percentage of rated capacity of boiler to be used for proportioning chimneys..........................	100	125	150	...	200	...	250	...

Another method of determining the volume of gases is to assume the weight of coal to be burned per horsepower and the probable excess air and make use of the chart on page 122, giving the volume of gases per pound of combustible approximately but sufficiently accurately for computations. This is redrawn after *G. Herberg*. The approximation assumes that the heat value is due entirely to carbon and that the ratio of air supplied to air required is the ratio of the maximum CO_2 percentage possible to the actual CO_2 percentage.

Having determined the quantity of gas per boiler H.P., either by computation or the table, determine the total gases to be handled, *i. e.*, assume the average CO_2 percentage expected and use the suggested percentage of rated capacity in the table.

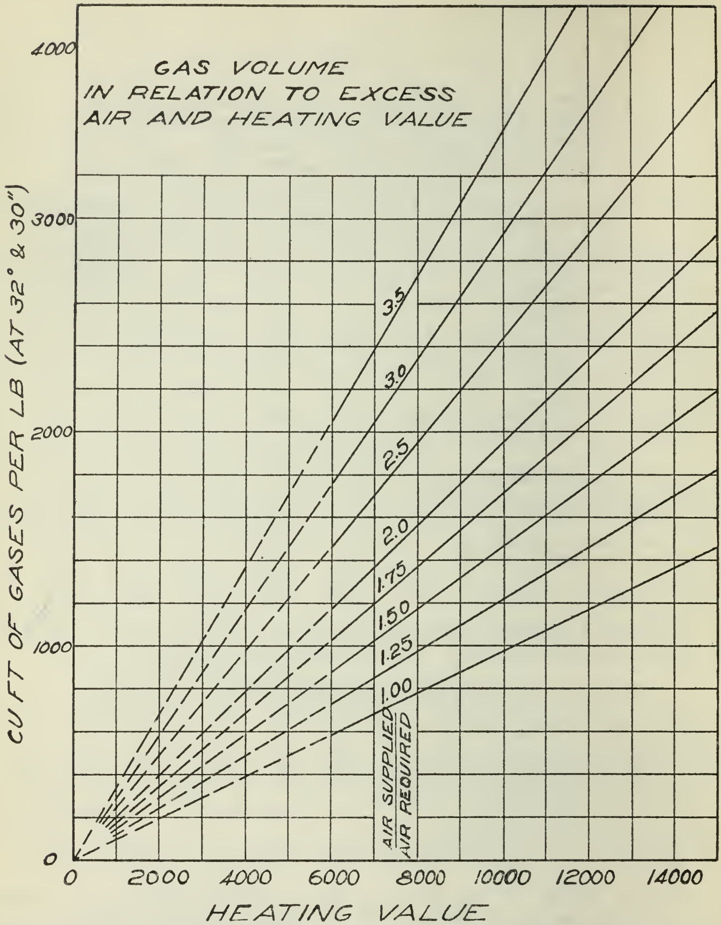


CHART FOR ESTIMATING THE VOLUME OF FLUE GASES UNDER STANDARD CONDITIONS (32° F. AND 30 IN. Hg) RESULTING FROM THE COMBUSTION OF 1 LB. OF COAL OF DIFFERENT HEATING VALUES WITH DIFFERENT PROPORTIONS OF AIR SUPPLIED

Assume three or four gas velocities with the intermediate one taken from the table below.

Assumed Economical Velocities for a First Approximation

Volume of gas to be removed in cu. ft. per sec.	10	50	150	500	1200	2500	5000	8000
Economical velocity in ft. per sec.	10	15	20	25	30	35	40	45

The area of a conduit is the total volume of gases handled divided by the velocity. Determine as below the heights of stacks of the diameters corresponding to the velocities assumed. See page 117 for a graphical method of determining area of gas passages.

The friction draft loss in the breeching or chimney, according to *Menzin*, is

$$P_r \text{ or } P_c = F \frac{l}{d} \left(\frac{v^2}{T_c} \right) \text{ in inches of water.}$$

F = coefficient = .008,
d = diameter in ft.,
l = length in ft.,
v = velocity in ft. per sec.,
T_c = abs. temperature of gases in deg. F.

The length of the breeching must include bends, etc. (See page 116.)

The curves on page 124 can be used to obtain the frictional loss of draft in the flues and stacks of the diameters corresponding to the assumed velocities.

The breeching loss must also include the loss due to sudden enlargements of gas passage, $P_v{}^1$.

$$P_v{}^1 = \frac{.123\ P\ (v_1 - v_2)^2}{30 T_c} \text{ wherein}$$

$P_v{}^1$ = draft loss in in. of water,
P = barometric pressure in in. of mercury,
v_1 and v_2 = velocities in ft. per sec.,
T_c = absolute temperature in Fahr. deg.

The general formula for determining the theoretical draft due to a given stack height is:—

$$P_z = 0.52 \quad HP \left(\frac{1}{T_a} - \frac{1}{T_c} \right)$$

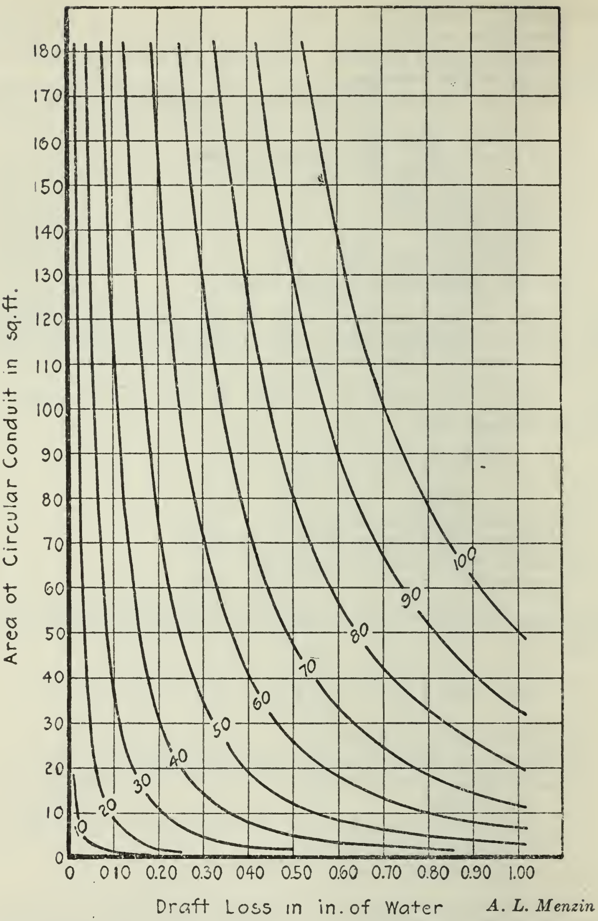
P_z = draft in in. of water,
H = height of stack above the grate bars in ft.,
P = atmospheric pressure in lbs. per sq. in. (14.7 lb. for average conditions),
T_a = absolute temperature of the atmosphere ($60 + 460 = 520$ degs. F. average conditions),
T_c = absolute temperature of the stack gases.

The formula assumes that the stack gases have the same density as air. The error due to this is negligible, as a correction factor is applied in practice.

The original formula (1), on page 120, can be written

$$(P_g + P_b + P_v) + P_d + P_r + P_c = P_z \qquad (2.)$$

The first three make up the draft required at the damper and their determination has been considered. P_d can be neglected as explained. The determination of P_r has been covered. P_c the friction loss in the stack itself and P_z the theoretical draft which the stack will supply include its height H. Their values per 100 ft. of stack can be determined as above. H can be determined from expression (2). Select the most suitable height and diameter of stack.



A. L. Menzin

DRAFT LOSS PER 100 FT. OF A CIRCULAR BRICK-LINED CONDUIT CORRESPONDING TO THE VELOCITIES IN FT. PER SEC. NOTED ON THE CURVES.

For barometer at 30-in. mercury and gases at 540 degs. F. For any other height or length H in ft., multiply by 0.01 H. For a square conduit of side equal to the diameter of a circular conduit, multiply by 0.62. For any other barometric pressure P in inches of mercury, multiply by 30/P. For any other gas temperature t in degs. F., multiply by 0.001 (t + 460).

The diagram on page 125, adapted from *M. Gensch,* illustrates draft relations as they affect the power capacity of a chimney. The upper curve represents the theoretical draft which a given stack would give at different loads. The draft is proportional to the product of the load and the difference of the reciprocals of the air temperature and the stack gas temperature in

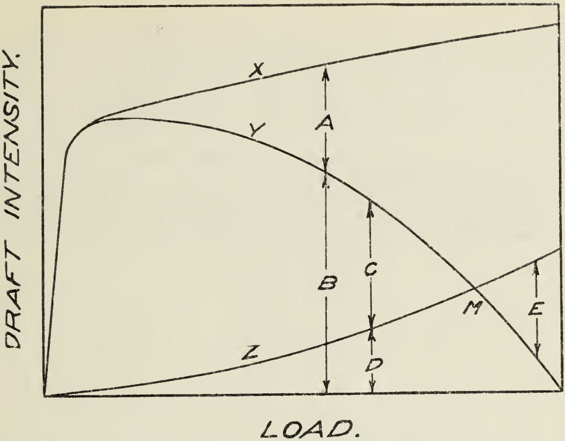
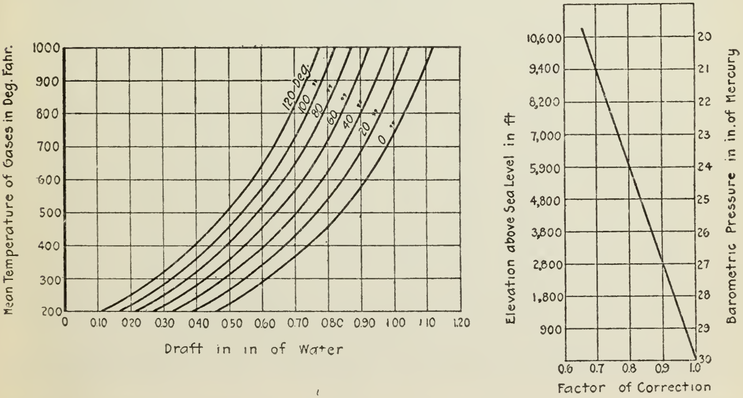


DIAGRAM SHOWING DRAFT RELATIONS WITH CHIMNEY DRAFT

absolute degrees. The pressure *A* required to overcome the resistance of the boiler, flues and stack is proportional to the square of the load. The middle curve was obtained by subtracting values proportional to the square of the load from the upper curve. It therefore represents the draft *B* available for overcoming the fuel bed resistance. The lower curve represents the draft *D* required by the fuel bed at the different loads. When the middle curve is above the lower one there is excess draft and the damper must be



MAXIMUM DRAFT AT SEA LEVEL PER 100 FT. OF CHIMNEY HEIGHT CORRESPONDING TO THE AIR TEMPERATURES NOTED ON THE CURVES.

For any other height H in ft., multiply by 0.01 H. For any other altitude or barometric pressure, multiply by the corresponding factor of correction from the curve on the right.

A. L. Menzin

partially closed, to use up by its resistance the draft represented by the distance *C* between the two curves. At load *M* the draft for the fuel bed is just sufficient for its requirements and the damper should be wide open so that it offers no resistance. The draft available for the fuel bed is not sufficient to increase the load beyond this point, and a mechanical draft arrangement must make up the difference represented by the distance *E* between the two curves.

Since the complete determination as outlined above may not be desired the following tables and data are included.

Kent's Chimney Table, given below, is reliable for ordinary rates of combustion for bituminous coals. When low grade Western bituminous coals are used, it is advisable to increase the size 25 to 60%.

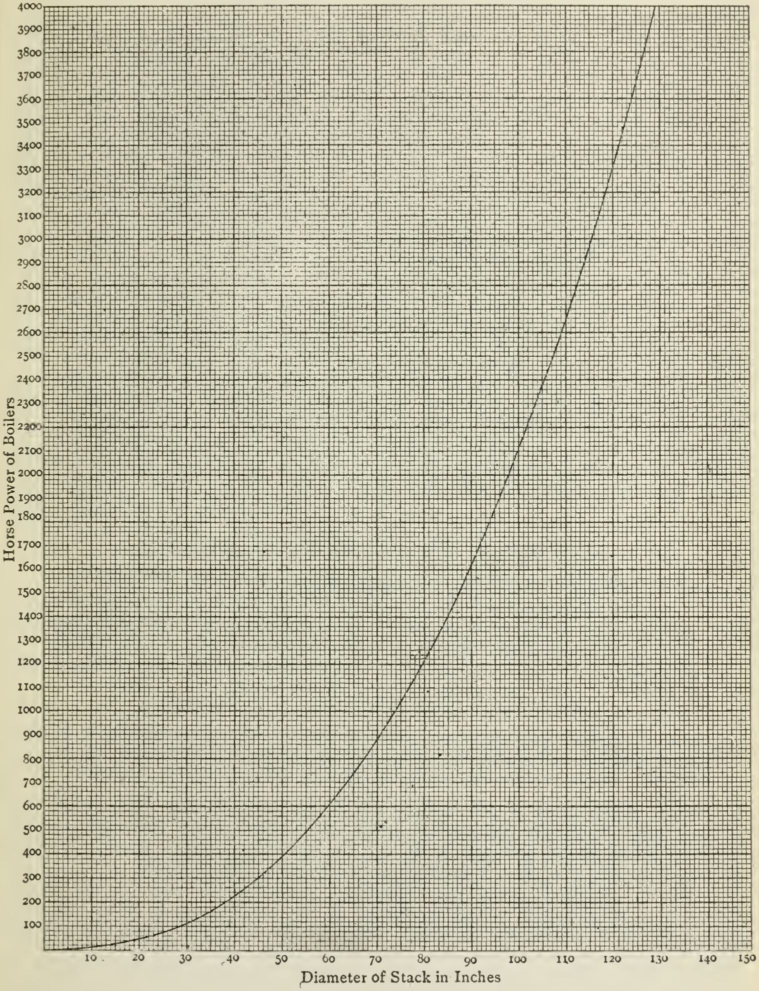
Diameter Inches	Area Square Feet	Height of Stack in Feet										Side of Equivalent Square Stack Inches	Diameter Inches
		50	60	70	80	90	100	110	125	150	175		
		Commercial Horse Power											
33	5.94	106	115	125	133	141	149	. .	. .	. .	. .	30	33
36	7.07	129	141	152	163	173	182	. .	. .	. .	. .	32	36
39	8.30	155	169	183	196	208	219	229	245	. .	. .	35	39
42	9.62	183	200	216	231	245	258	271	289	316	. .	38	42
48	12.57	246	269	290	311	330	348	365	389	426	460	43	48
54	15.90	318	348	376	402	427	449	472	503	551	595	48	54
60	19.64	400	437	473	505	536	565	593	632	692	748	54	60
66	23.76	490	537	580	620	658	694	728	776	849	918	59	66
72	28.27	591	646	698	747	792	835	876	934	1023	1105	64	72
78	33.18	700	766	828	885	939	990	1038	1107	1212	1310	70	78
84	38.48	818	896	968	1035	1098	1157	1214	1294	1418	1531	75	84

		Height of Stack in Feet									
		100	110	125	150	175	200	225	250		
		Commercial Horse Power									
90	44.18	1338	1403	1496	1639	1770	1893	2008	2116	80	90
96	50.27	1532	1606	1713	1876	2027	2167	2298	2423	86	96
102	56.75	1739	1824	1944	2130	2300	2459	2609	2750	91	102
108	63.62	1959	2054	2190	2392	2592	2770	2939	3098	98	108
114	70.88	2192	2299	2451	2685	2900	3100	3288	3466	101	114
120	78.54	2438	2557	2726	2986	3226	3448	3657	3855	107	120
126	86.59	2697	2829	3016	3303	3568	3814	4046	4265	112	126
132	95.03	2970	3114	3321	3637	3929	4200	4455	4696	117	132
144	113.10	3554	3726	3973	4352	4701	5026	5331	5618	128	144
156	132.73	4190	4393	4684	5131	5542	5925	6285	6624	138	156
168	153.94	4878	5115	5454	5974	6454	6899	7318	7713	150	168

STACK SIZES BY KENT'S FORMULA, ASSUMING 5 LB. OF COAL PER HORSE-POWER HOUR.—*Steam.*

The curve on page 127, from *Steam*, shows the horse-power which can be developed from a given diameter of stack.

The table on page 128 shows the available draft for different diameters of stacks and different horse-powers.



RELATION OF DIAMETER OF STACKS AND HORSEPOWER THEY WILL SERVE, COMPUTED FROM THE FORMULA, DIAM. $= 4.68 \text{ (HP.)}^{2/5}$. FOR BRICK OR BRICK-LINED STACKS, INCREASE THE DIAMETER 6%.

Horse Power	Diameter of Stack in Inches															Horse Power	Diameter of Stack in Inches							
	36	42	48	54	60	66	72	78	84	90	96	102	108	114	120		90	96	102	108	114	120	132	144
100	.64															2600	.47	.53	.56	.59	.61	.62	.64	.65
200	.55	.62														2700	.45	.52	.55	.58	.60	.62	.64	.65
300	.41	.55	.61													2800	.44	.50	.55	.58	.60	.61	.64	.65
400	.21	.46	.56	.61												2900	.42	.49	.54	.57	.59	.61	.63	.65
500		.34	.50	.57	.61											3000	.40	.48	.53	.56	.59	.61	.63	.64
600		.19	.42	.53	.59											3100	.38	.47	.52	.56	.58	.60	.63	.64
700			.34	.48	.56	.60	.63									3200		.45	.51	.55	.58	.60	.63	.64
800			.23	.43	.52	.58	.61	.63								3300		.44	.50	.54	.57	.59	.62	.64
900				.36	.49	.56	.60	.62	.64							3400		.42	.49	.53	.56	.59	.62	.64
1000				.29	.45	.53	.58	.61	.63	.64						3500		.40	.48	.52	.56	.58	.62	.64
1100					.40	.50	.56	.60	.62	.63	.64					3600			.47	.52	.55	.58	.61	.63
1200					.35	.47	.54	.58	.61	.63	.64	.65				3700			.45	.51	.55	.57	.61	.63
1300					.29	.44	.52	.57	.60	.62	.63	.64	.65			3800			.44	.50	.54	.57	.61	.63
1400						.40	.49	.55	.59	.61	.63	.64	.65	.65		3900			.43	.49	.53	.56	.60	.63
1500						.36	.47	.53	.58	.60	.62	.63	.64	.65	.65	4000			.42	.48	.52	.56	.60	.62
1600						.31	.43	.52	.56	.59	.62	.63	.64	.65	.65	4100			.40	.47	.52	.55	.60	.62
1700							.41	.50	.55	.58	.61	.62	.64	.64	.65	4200			.39	.46	.51	.55	.59	.62
1800							.37	.47	.54	.57	.60	.62	.63	.64	.65	4300				.45	.50	.54	.59	.62
1900							.34	.45	.52	.56	.59	.61	.63	.64	.64	4400				.44	.49	.53	.59	.62
2000								.43	.50	.55	.59	.61	.62	.63	.64	4500				.43	.49	.53	.58	.61
2100								.40	.49	.54	.58	.60	.62	.63	.64	4600				.42	.48	.52	.58	.61
2200								.38	.47	.53	.57	.59	.61	.62	.64	4700				.41	.47	.51	.57	.61
2300								.35	.45	.52	.56	.59	.61	.62	.63	4800				.40	.46	.51	.57	.60
2400								.32	.43	.50	.55	.58	.60	.62	.63	4900					.45	.50	.57	.60
2500									.41	.49	.54	.57	.60	.61	.63	5000					.44	.49	.56	.60

FOR OTHER STACK TEMPERATURES ADD OR DEDUCT BEFORE MULTIPLYING BY HEIGHT ÷ 100 AS FOLLOWS*

For 750 Degrees F. Add .17 inch. For 700 Degrees F. Add .14 inch.	For 650 Degrees F. Add .11 inch. For 600 Degrees F. Add .08 inch.	For 550 Degrees F. Add .04 inch. For 450 Degrees F. Deduct .04 inch.	For 400 Degrees F. Deduct .09 inch. For 350 Degrees F. Deduct .14 inch.

AVAILABLE DRAFT CALCULATED FOR 100 FT. STACK OF DIFFERENT DIAMETERS, ASSUMING STACK TEMPERATURE OF 500° F. AND 100 LB. OF GAS PER HP. FOR OTHER HEIGHTS OF STACK MULTIPLY BY HEIGHT/100.

When small sizes of anthracite are to be burned, the stack height for natural draft becomes prohibitive, and mechanical draft must be utilized. To burn 25 lb. of pea coal per sq. ft. per hr. requires a 175 ft. stack. To burn the same quantity of No. 3 buckwheat requires a 385 ft. stack.

Osborne Monnett made the following recommendations to the Smoke Prevention Association: Stacks should be so located as to give the most favorable run of breeching possible. Steel stacks should be lined for a height equal to 10 times their diameter. For water-tube boilers the free area of the stack at the smallest point should be not less than one-fifth the area of the total connected grate surfaces, where the stack is less than 150 ft. high. Where the stack is over 150 ft. high, the area should be not less than one-sixth the total grate surface. For horizontal return-tubular boilers the stacks should have an area in free opening at the smallest point 25% in excess of the combined area of the tubes served.

The following remarks about draft and chimney heights are due to *E. A. Uehling:* The intensity of draft produced by a given chimney increases with the gas temperature. All useless loss of temperature, such as radiation from the uptake and flues and leakage of cold air into the flues and chimney, must be avoided. Natural draft is greatly affected by atmospheric conditions. Barometric pressure, temperature and humidity all have their effects upon the draft from a given chimney. Chimneys at high altitudes must be higher and larger than at sea level because of the lower barometric pressure and the lower density of the air. Even at sea level the barometric pressure may vary from 28 to 31 in., which produces a variation of 9.68% in the effectiveness of the draft. Since natural draft depends primarily on the difference in temperature between the gas inside and outside the chimney, it will be affected as much by changes of temperature outside as by changes in the temperature of the gas in the chimney. Assuming a uniform stack temperature of 500° F., a chimney would show 41% greater draft with an atmospheric temperature of 20° below zero than with an atmospheric temperature of 100° above. Draft is better in clear, dry weather than in hot, sultry or foggy weather. This is due to a lower barometric pressure in the latter case, and to the fact that the water vapor which displaces air weighs less than air and a larger volume of air is required for given combustion conditions. Besides displacing air, the water vapor absorbs heat and retards combustion in the fuel bed. The effect of a brisk wind in the right direction is well known, although its influence cannot be even approximately calculated. The variations in the atmosphere rarely occur to the full extent and probably never at the same time, and one condition may neutralize largely the effects of the others.

DRAFT REQUIRED BY STOKERS

The following brief statements regarding the draft required by stokers and their fuel and load adaptations are due to the respective makers: The maximum possible rating with a given boiler is made up of two factors, rate of combustion per sq. ft. of grate area and area available for grates. See pages 84 to 99 for distinctive features.

CHAIN OR TRAVELING GRATES

Illinois Stoker Co.—The grate is particularly adapted to Illinois, Kansas, Iowa, Ohio, Arkansas, Texas and other Middle Western coals high in ash (22 to 25%). Lower ash coals (10 to 13%) can also be burned. With high-ash coals a draft of .63 in. over the fire and 1 in. at the damper will burn 42 lb. of coal per sq. ft. of grate surface per hr. The best depth of fuel bed is 5½ to 6 in. With lower ash coals, the draft over the fire should be approximately .4 in., when burning the same amount of coal. It has been found that the rate of combustion varies nearly proportionally to the square root of the draft in the fire box. With the forced draft type of grate, the draft over the fire varies from atmospheric pressure to .15 in. water, while pressures in the wind box vary from 1 in. to 4 in. water.

Rosedale Foundry & Machine Co.—The Playford Chain Grate Stoker is made in two forms, the Standard Type A and Special Type B. Type A corresponds to other standard makes, with its own distinctive features, while special Type B is for larger units operating under heavy continuous overloads, and is heavier. Bituminous coals ranging from 25 to 40% volatile are best adapted. The stoker will develop 150 to 200% of rating continuously with no extra attention. Natural draft is used. For ordinary load .15 to

.3 in. draft in the fire box is required, and for the maximum load .25 to .40 in. draft. Variable load may be carried by changing the thickness of the fire, the feed and the damper position.

Westinghouse Electric & Mfg. Co.—The Westinghouse Chain Grate Stoker is used only with natural draft and with free burning coals. A minimum draft of .25 in. in the furnace should be available for ordinary operation, and up to as high as .6 in. for higher capacity. Under favorable fuel, draft and setting conditions, 50 lb. of coal per sq. ft. of grate surface per hr. can be burned.

Babcock & Wilcox Co.—The B. & W. Chain Grate Stoker is adapted to Illinois, Indiana, Colorado, Montana, Pittsburgh and Youghiogheny and similar coals. It is used with natural draft in the majority of cases, although there are a number of satisfactory forced draft installations. With the ordinary grate ratio, boiler capacity can be developed with .25 in. pressure drop through the fuel bed; .75 in. will develop 100% overload. All coals suitable for chain grates are stated to have a maximum combustion rate regardless of draft.

Green Engineering Co.—Approximately 10 lb. of coal can be burned per sq. ft. per hr. for each .1 in. draft available in the furnace. Combustion rates up to 60 lb. have been obtained but the usual proportion of grate required only 30 to 40 lb Natural draft is used with the "K" type for free burning coals, and .6 in. drop would be required through the fuel to burn 50 lb. per sq. ft. per hr. Either natural or forced draft is used with "L" type (having an inclined coking plate at the front of the traveling grate and used for coking coals) The same pressure drop through the fuel bed as for the "K" type is required Induced draft under some conditions, such as high altitude or with economizers, is more desirable than natural draft. 250% and higher loads are possible.

Coxe Traveling Grate Co.—The Coxe Traveling Grate was originally designed for anthracite rice, but has been developed for any size anthracite, coke breeze and bituminous. It is used only with forced draft. With 2.5 in. pressure in the ash-pit, 150 to 200% load can be carried continuously; 300% is not unusual.

Combustion Engineering Corporation.—The Coxe Traveling Grate as made by this concern is designed for small anthracite coal and coke breeze, but will also handle successfully free burning coal high in ash. Forced draft at a pressure of 1 to 2 in. under the grate is used. By properly proportioning the grate surface to the heating surface, it is possible to obtain continuous ratings of 200% of boiler rating with excellent economy.

It is possible to burn coke breeze and No. 3 buckwheat anthracite at rates of combustion as high as 40, 45 and 50 lbs. per sq. ft. of grate surface.

Laclede-Christy Chain Grate.—This stoker is designed for the coal mined west of the Indiana-Ohio line. Eastern coals to which it is fitted are free-burning bituminous, such as Youghiogheny, Westmoreland and Pittsburgh. The stoker uses natural draft. With chimneys 175 to 250 ft. high, capacities up to 200 to 300% ratings are obtained.

OVERFEED STOKERS

Westinghouse Electric & Mfg. Co.—The Westinghouse-Roney Stoker is adapted to either coking or free-burning coals, and uses natural draft. Ordinary operation requires .25 in. draft, while for maximum load .6 in. is required. With free-burning coals the maximum rate of combustion is 50 lb. per ft. per hr., while with high-carbon coking coals the maximum is 35 lb. per sq ft. per hr.

Wetzel Mechanical Stoker Co.—Natural draft is ordinarily used, but forced draft is often employed for overloads greater than 200%.

Murphy Iron Works.—The Murphy Stoker uses natural draft, and for ordinary loads requires .25 in., while for maximum load .50 in. 150% rating is usual, and 200% rating is easily and economically carried. 300% of rating was obtained with .8 in. to 1 in. pressure in the ash-pit and a combustion chamber vacuum of about .05 in.

UNDERFEED STOKERS

American Engineering Co.—The Taylor Stoker is adapted to bituminous, semi-bituminous and semi-anthracite coals, while lignite gives very fair results. Forced draft only is used. For normal ratings 1.5 to 2 in. pressure in the wind box is used, with .03 in. suction in the furnace. For maximum load, 3 to 4 in. in the wind box is required and .05 in. suction in the furnace. Long continued loads of 200 to 300% of rating are maintained, while much higher peaks can be handled up to 350%. Forced draft permits perfect mechanical control of the air supply. It is independent of weather conditions, and is intense enough to burn low-grade coals. The stoker and the air fan are driven by the same motor or engine. The normal rate of combustion is 30 to 40 lb. per sq. ft. per hr., but 60 to 80 lb. can be burned during short peaks. Boilers can be brought up to 250% load from banked fires in 10 to 15 min.

Sanford Riley Stoker Co., Ltd.—The Riley Stoker is adapted to all grades of bituminous coals, such as West Virginia and Pennsylvania grades, down through to the Illinois and Indiana varieties and the Western lignites. Forced draft is used with pressures in the wind box of from 0 to 5 in., depending upon the rating at which the boiler is operated. Peak load operation at from 200 to 300% of rating is normally obtained. There should be a slight suction present in the furnace at maximum capacity. The question of capacity depends upon the size of the stoker in relation to the boiler. At the plant of the Buffalo General Electric Company two 15-retort Riley Stokers are installed back to back under 1140 HP. B. & W. boilers. Under these conditions, normal operation is 300% of rating and it is possible to burn sufficient coal to obtain 500% or even higher ratings.

Westinghouse Electric & Mfg. Co.—The Westinghouse Stoker always uses forced draft, although moderate ratings can be secured on natural draft. No statement of the relation between air pressure under the stoker and combustion rates can be made that will be of a general application, because the size, moisture content and other characteristics of the fuel all affect the air pressure required. Air pressures of from 6 to 7 in. in the stoker wind box can be utilized for high rating. Westinghouse Underfeed Stokers are developing over 400% rating for daily peak load service.

Combustion Engineering Corporation.—The Type "E" Stoker will readily handle all grades of semi-anthracite, semi-bituminous and sub-bituminous coals, such as New River, Pocahontas, Clearfield, Youghiogheny, Ohio, Illinois and Iowa coals. Forced draft is always used. The wind box pressure should run from 1 to 5.5 in., and the draft suction at the fuel bed .05 in. at least. In general 1 in. of air pressure in wind box for each 10 lbs. of coal per sq. ft. per hr. is required and is always sufficient. 200 to 225% of rating may be maintained continuously and 300 to 350% for short periods of from 2 to 4 hrs.

Lehigh Stoker Co.—The Lehigh Stoker is made in two forms. The natural draft type is adapted to all grades of bituminous coal and under ordinary operation requires .25 in. draft over the fire, when boilers are operating at rating, and .5 in. when operating at 200% of rating. The forced draft type is adapted to all grades of bituminous coal, all grades of anthracite coal and coke breeze. The pressure in the wind box varies from 1 to 3 in. according to the kind of fuel burned, and ratings of 150 to 200% can be maintained continuously.

Moloch Stoker Co.—The Moloch is an underfeed, self-cleaning stoker, for bituminous and semi-bituminous coals. Forced draft is used for the air supply, but because of the large tuyere area, a considerable capacity can be developed with natural draft of .3 to .45 in. water gauge, and 3.5 to 4 in. water gauge air pressure will make it possible to burn enough coal to obtain a rating from the unit, up to the ability of the boiler to absorb the heat generated and the ability of the furnace brick-work to withstand the temperature produced.

Nelson Blower and Furnace Co.—With the Stevens Stoker, if there is a ¼ in. draft over the fire, the rated boiler horse-power can be developed on natural draft. It will handle bituminous and semi-bituminous coals. An ash-pit pressure of 1 in. developed by a blower will produce 200% rating and over.

MECHANICAL DRAFT

The capacity to be provided in mechanical draft fans depends upon the quantity of gases to be handled. Assuming 5 lb. of coal per boiler HP. and 24 lb. of flue gases per lb. of coal, there would be 120 lb. of flue gases per boiler HP. per hour, which would cover usual overloads and poor coal. The volume is easily computed from the density of the gases at the stack temperature. Also see determination of volume under "Stack Proportions." The sizes of fans can be obtained from the manufacturer.

Induced Draft.—Fans for this service handle gases at high temperature and frequently heavily dust laden, occasioning excessive maintenance cost. The volume of gases passing through an induced draft fan is much greater than would be handled by a forced draft fan, and it might seem that the forced draft apparatus could be used to advantage in all cases. However, it is important in most cases that a draft suction be maintained in the boiler setting, and this may necessitate an induced draft fan. There is even distribution of the draft over the fuel bed. The steam consumption of an induced draft fan will be approximately 2 to 4% of the steam generated.

Forced Draft.—In a forced draft installation it is desirable that the stack be capable of maintaining a suction throughout all parts of the boiler setting. If such suction is not maintained, trouble will result with the brick work, as high temperature gases will tend to pass out through the cracks and pores in the setting, overheating it, whereas with draft suction cold air from the outside percolates in through the brick work, and reduces its temperature. This suction is also necessary to secure the inflow of the proper amount of secondary air. The ash-pit must be air-tight. The air must be introduced in such manner as to give an even pressure distribution over all portions of the grate, in order that the fire may burn evenly. The power consumption of a forced draft fan should be less than that of an induced draft fan, because of the lower temperature, and hence smaller volume, of the cold air as compared with the chimney gases. The actual steam consumption of forced draft fans varies from 2% of the total steam generated often to much higher figures, due to the use of small, inefficient fans or small, cramped ducts.

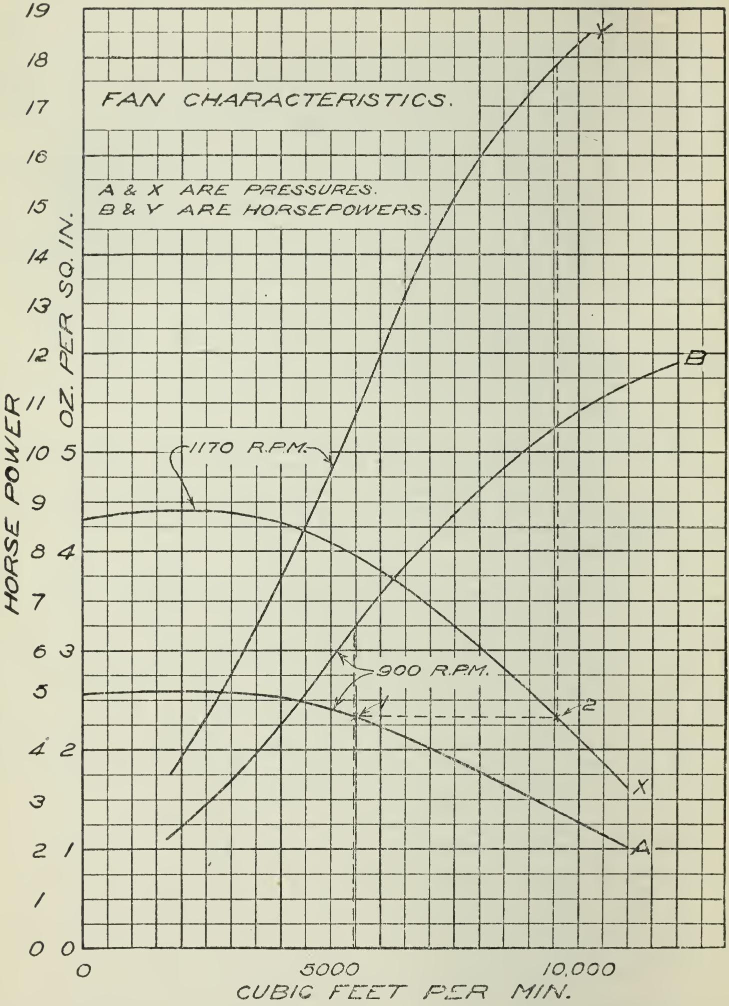
Steam Jet.—The jets may be placed either in the ash-pit or in the flue, producing either forced or induced draft. The advantage of producing draft by a jet lies almost entirely in its cheapness of installation and low cost of repair. Its use is confined to small plants where the cost of a fan is not warranted, and to use in larger plants for carrying short peak loads. Its disadvantages are large steam consumption, limitation of draft produced, and noise.

A. D. Pratt states that the maximum ash-pit blast that can be obtained from jets is approximately 1 in. of water, while draft suction in the flue can be produced up to ¾ in. above that which the stack alone would give. A ring of jets should be used in the stack to produce any appreciable results. The steam jets must be properly placed in the ash-pit in order to give an even distribution of draft pressure and thus produce an even fire. Steam consumption may run as high as 30% of the total steam generated, an ordinary figure being 5 to 10%. Under test conditions, figures as low as 2½% have been obtained. 4 to 6% will probably be good average practice.

The *Bureau of Mines* warns that the attempt must not be made to put more air through existing boilers by overspeeding fans, since the power consumption will increase too rapidly. With a constant thickness of fuel bed, doubling the weight of air requires about 3½ times the draft pressure difference, and trebling the weight of air about six times the draft pressure. In the first case, the fan would require 6½ times the weight of steam, and in the second case, 18 times the weight of steam. Therefore more efficient fans and more efficient engines must be obtained if grate surface and boiler are to be driven at very high ratings. Provided the boiler is such that the efficiency does not drop off too much when the capacity is increased, and the fuel is not easily carried from the fuel bed, an increase in rating is a sound step commercially. The steam from the fans can generally be used in a feed water heater.

The effect of running a fan under conditions different from those for which it is designed is shown by curves on page 134. Fan manufacturers specify that a certain fan will deliver a certain number of cubic feet of air at a certain pressure when running at a certain speed. If, with the speed of the fan constant, the size of the opening be increased, more air will be delivered, but at lower pressure.

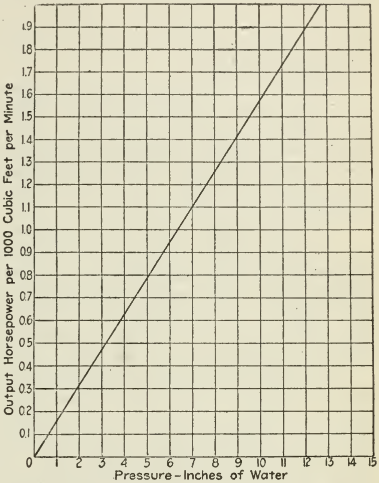
At a speed of 900 rpm. the performance of a fan might be represented by the line *A*, while the horse-power taken by the fan would be represented by the line *B*. The first part of the pressure curve *A* is nearly horizontal, the point No. 1, where the line has taken a decided bend, is the delivery corresponding to what is usually termed the "blast area" of the fan, that is, the largest orifice over which the fan will maintain approximately its maximum pressure. Fans are usually operated at some rate of delivery beyond point 1. If the speed of the fan be increased to 1170 rpm., the pressure at any given output will be increased, and the new characteristic curve will be *X*, while the power consumption curve will be *Y*. If the volume of air delivered be the same as for the lower speed, the fan is capable of maintaining a higher pressure, while if the pressure at which the air is required is the same as before, the fan is capable of delivering a much greater volume but in general with a still greater increase in power consumption. For instance, the power required when running at 900 rpm. for the delivery at point 1, is 6.4 HP. With the same pressure, the fan running at the higher speed of 1170 rpm. would give the increased volume shown at point 2, but would require the much increased power of 17.9 HP. Where the size of the openings and the length of the pipe remain constant, the volume of air handled by the fan increases almost directly as the speed, the pressure increases as the square of the speed, and the power consumed increases as the cube of the speed. That is, by doubling the speed, twice the amount of air will be handled, at a pressure four times as great as before, and using eight times as much power for



CURVES SHOWING THE EFFECT ON FAN CHARACTERISTICS OF INCREASING THE CAPACITY BY AN INCREASE OF SPEED the fan. It is readily seen, therefore, that if more air is required, but not more pressure, it is generally poor policy to obtain increased volume of air by speeding up the fan. It would be better to install a larger fan or to add a second one.

Mechanical draft is affected by the state of the atmosphere in the same way as is natural draft, but the deficiency can be supplied by increasing the speed of the fan.

The air horse-power corresponding to the delivery of 1000 cu. ft. of air per minute at different pressures is given by the adjoining chart by *J. L. Alden.* In formula this is HP. per 1000 cu. ft. per minute = .157 × pressure (in inches of water). To obtain the shaft horsepower this should be divided by fan efficiency.

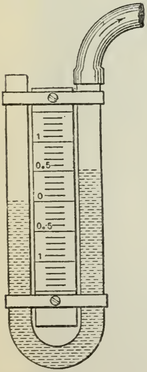


FAN HORSEPOWER REQUIRED FOR VARIOUS PRESSURES

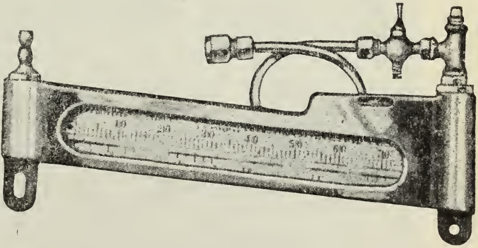
DRAFT GAUGES

The simple draft gauge indicates the difference in pressure between the point to which it is connected and the atmosphere. A differential draft gauge indicates the difference in pressure between two points in the gas passages.

Ordinary draft gauges are modified forms of the U-tube. As the pres-



U-TUBE DRAFT GAUGE



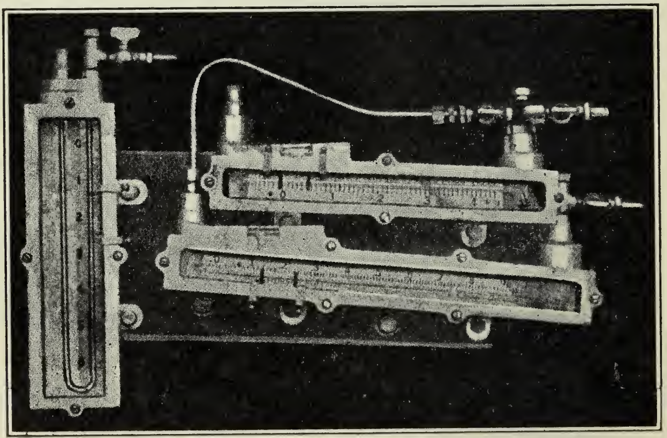
HAYS DIFFERENTIAL DRAFT GAUGE

sures are usually very small, water or oil is used as the liquid in the tube. Oil has greater uniformity of capillary attraction and minimum evaporation. Gauges are calibrated for a given mineral oil which is usually colored red and the specific gravity of the proper oil must be known in making a replacement. For greater accuracy in reading the pressure, one leg of the tube is sometimes inclined.

Efficient combustion requires that a certain amount of air be provided for each pound of fuel burned. When combustion is progressing properly, the quantity of gases will be in direct proportion to the boiler load. The gases pass through the boiler, which has a constant resistance. A differential draft gauge indicating the pressure drop through the boiler will therefore act as a gas flow meter and show whether the proper quantity of air is being supplied for a given load.

A draft gauge connected to show the pressure drop through the fuel bed in connection with one showing the drop through the boiler will indicate any change in the fuel conditions. A relative increase in the fuel bed drop will indicate that the bed is becoming thicker, or that it is becoming clogged with clinker, etc. Similarly, if the pressure drop becomes less, it indicates that there are holes in the fire, or that the fuel bed is too thin. The above principles are made use of in so-called combustion meters and efficiency indicators.

The **Ellison** multiple differential draft gauge consists of multiple gauges and a U-gauge mounted on the same base, complete with connections and dust-proof vent caps. The U-gauge indicates the blast, the upper inclined gauge the furnace draft and the lower inclined gauge the drop between the flue and furnace (boiler resistance). Each gauge has movable pointers, the range of each scale being indicated. For balanced draft the furnace gauge has a scale reading 0.05 in. to the left of zero for momentary pressures in the furnace above the atmosphere and 0.45 in. to the right of zero for the suction, the liquid movement being multiplied 15 times. On this gauge the indicating tube lies near the upper edge of the scale, bending down at the chamber to prevent the liquid pulling through from a momentary excess furnace draft.



ELLISON U-MULTIPLE DIFFERENTIAL DRAFT GAUGE

The **Blonck** Efficiency Meter consists of two differential draft gauges, the one indicating the pressure drop through the boiler and the other the pressure drop through the fuel bed.

The **Bailey** Boiler Meter combines the "efficiency meter" with a steam-flow meter. The two draft gauges are of the recording type, and are enclosed in the same case with the steam flow meter, recording on one circular chart. The pressure drop in the boiler gas passages is an indication of the quantity of air passing through the boiler, and the pen recording this pressure is set to record just ahead of the steam flow pen. When the two lines practically coincide, the air is in the proper proportion for the load on the boiler. A pen controlled by two differential pressure meters of the inverted bucket type attached to the arms of a balance, called the furnace indicator, records on the outer portion of the chart. The steam record is made as a percentage of the rated capacity of the boiler.

The pressure drop across the fire varies with the resistance of the fuel bed, and also with the rate of flow of air through the fuel bed. The furnace indicator compares the pressure drop across the fire with the pressure drop across the boiler, eliminating effects due to the rate of flow of air and thus obtains a net result which varies only with the resistance of the fuel bed. While this type of apparatus indicates what is going on in the furnace and boiler, the operator must have sufficient intelligence and skill to be able to interpret its indications and adjust the conditions.

Figures on page 138 show the proper locations of draft connections. Where possible, the two connections for a differential gauge should be placed on the same level, in order to eliminate errors in draft readings due to the difference in weight of the columns of gas in the pipe connections and in the furnace. For the boiler draft gauge the connections can readily be put on one level. For the gauge across the fuel bed, the two connections must necessarily be 18 or 20 inches apart vertically. However, this introduces but a slight error.

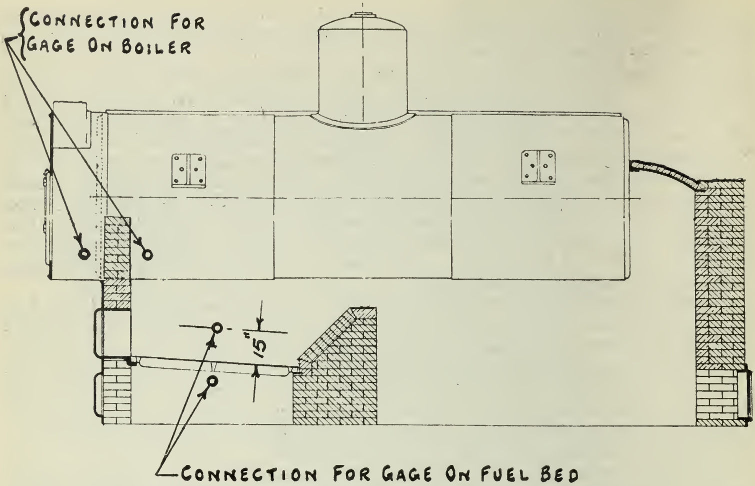
DAMPERS AND THEIR USE

According to *Osborne Monnett* dampers for horizontal return-tubular boilers should occupy the full width of the available opening and have a free area 25% in excess of the combined tube area. No type of damper plate that restricts the opening should be used.

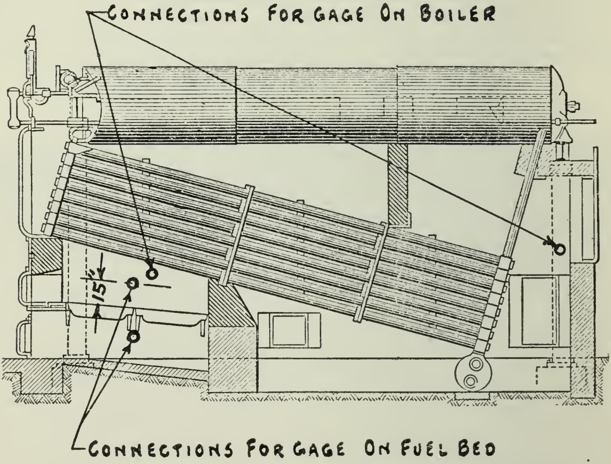
For water tube boilers, a free opening of one quarter the grate surface should be provided and the dampers when wide open should hang in such a manner as not to obstruct the movement of the gases. He recommends that no damper be placed in the main breeching.

To calibrate the damper, connect a differential draft gauge around the damper. Place the damper in the extreme closed position, open gradually and mark the position when the draft gauge is first affected. Continue opening the damper until the gauge registers no draft drop. Mark this position. Adjust the damper to work between these two positions.

There are two classes of damper regulators, first, machines that move the damper for slight changes of steam pressure, the movement being more or less proportional to the change of pressure, and second, machines that swing the damper between extreme positions when the steam pressure changes. *Hays* says that the first class is the better. The second does not meet the requirements of economical combustion. With the damper open, CO_2 percentage falls, due to air excess. With the damper closed, CO forms, due to lack of air. Machines of the first class may not make as perfect a steam pressure curve as the second, but will show better economy. Automatic regulators are not entirely satisfactory from the economic combustion standpoint.



LOCATION OF DRAFT GAUGE ON H. R. T. SETTING


CONNECTIONS FOR GAGE ON BOILER
15"
CONNECTIONS FOR GAGE ON FUEL BED

LOCATION OF DRAFT GAUGES ON B. & W. SETTING

The *Bureau of Mines* says to use high draft with high rates of combustion, and low draft with low rates of combustion. It is impossible to get a high rate of combustion with a low draft, but very frequently high draft is used for low rates of combustion, using 30 to 40 lbs. of air where 15 should be used. Regulate the draft by the damper. Arrange the latter so that the fireman can easily set it from the floor level.

Many serious cases of draft trouble could be cured by adjusting the boiler dampers to equalize the draft among the boilers. To equalize the draft among the boilers, get the fires all in standard condition, that is, the same thickness, free from air holes and clinkers. Adjust each boiler damper to the standard draft. Thereafter the main breeching damper alone should be used to regulate the draft to meet the load.

Change the position of the damper gradually. If the steam pressure is high, the damper should not be closed off entirely in order to let the pressure drop, then opened full to get the pressure up. This causes the draft and the air supply to vary excessively. Poorly adjusted automatic dampers cause similar variations.

Draft regulation by the ash-pit doors has very bad effects. It shuts off the air supply through the fuel bed, the ash on the grates and the grate bars becomes heated, and clinker and warped grates result. It is true that closing the ash-pit door cuts down the air supply, reducing the rate of combustion, but the draft in the setting is increased and more air is drawn into the furnace and all parts of the setting through the doors and cracks, entirely out of proportion to the coal burned. Air enters through the fuel bed, the furnace doors and cracks in the setting and by closing the breeching damper all are reduced in proportion. By closing the ash-pit door, the supply through the fuel bed is reduced, but all the others are increased.

FLUE GAS TEMPERATURE

Flue gas temperatures are nearly always taken with mercurial thermometers. Such thermometers are accurate, and are easy to read. Expansion pyrometers are unreliable. The *Bureau of Mines*, in its St. Louis tests, used mercury thermometers reading to 1000° F., 30 in. long, and graduated for 12 in. An air thermometer, consisting of a bulb in the flue connected by a half-millimeter copper tube to a recording pressure gauge, was also used. The volume of the bulb was very large compared to the tube.

Base metal thermocouples are satisfactory for indicating flue-gas temperatures when used in connection with a potentiometer, which eliminates effects of resistance and length of leads and compensates automatically for cold end temperatures. A continuous record of flue-gas temperatures is quite advantageous and can be obtained by using recording potentiometers, which are automatically self balanced. Potentiometer recorders are built as single-point curve-drawing instruments, and as multiple-point recorders, and a single instrument of the latter type can be used to record on one chart the individual flue-gas temperatures of as many as 16 different boilers or the temperatures at as many different points in one boiler setting.

Hays suggests that in reading flue-gas temperatures, care be taken to secure the average, and to protect the thermometer by petticoats from radiation. The temperature should be taken at the same point as the gas sample, *i. e.*, where the gases leave the heating surfaces of the boiler. This is especially important in obtaining an accurate heat balance, for if air leakage takes place after the pyrometer and before the sampling tube, the heat balance will show too high a loss up the stack. The bulb must be in the path of the moving gases, and must be in place long enough to assume the full temperature of the gases.

P. C. Linde suggests that if each boiler is equipped with pyrometers, so that the fireman can ascertain the temperature in each pass, he can tell the condition of the furnace and the boiler, that is, whether the fires are dirty, whether they have holes in them, whether the boilers are dirty inside or outside, whether the baffles are breaking down. However, he cannot tell which one of these troubles is producing the effect. The flue-gas temperature will indicate the necessity of cleaning the boilers. The temperature at full load should be taken at specified times, say every 24 hours. The temperature immediately after cleaning the boiler can be used as a standard. If the flue-gas temperature is say 150° higher for the full load than the standard, or the economizer gas temperature 100° higher, the boiler needs cleaning.

In *Bureau of Mines* tests on a large number of coals the flue-gas and combustion chamber temperatures rose and fell together. If low flue-gas temperature is to be accompanied by high efficiency, the combustion temperature should be made low by having the boiler receive a part of the heat of the gases directly by radiation from the fuel bed. The *University of Illinois* made tests on a Heine boiler with T-tiles which leave the undersides of the tubes in the lowest row bare, and with C-tiles which completely encircle lower row of tubes, with the following results:

	C-tile	T-tile
Capacity	102.8	104
Efficiency	65.6	68.5
Temperature above fuel bed	2066	1883
Flue-gas temperature	558	467
CO_2	6.8	7.5

Assuming a constant specific heat of the flue gases, and neglecting radiation losses, the efficiency of a boiler as an absorber of heat from the gases is equal to

$$\frac{t_1 - t_c}{t_1 - t_b}, \text{ wherein}$$

t_1 is the temperature of the gases just before contact with the heating surfaces,

t_c is the temperature of the gases just after leaving the heating surfaces, and

t_b is the temperature of the boiler.

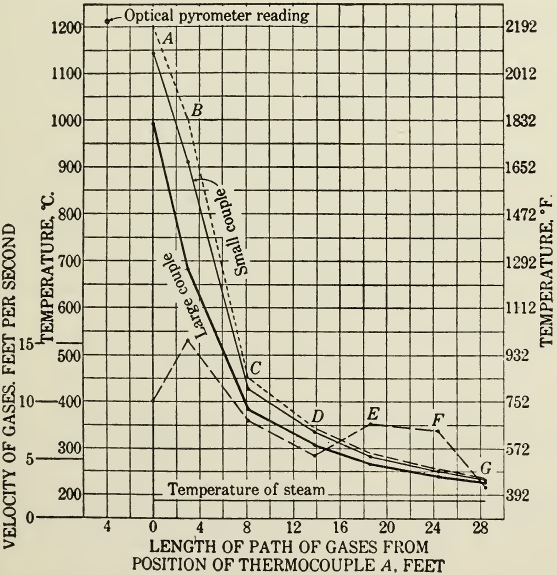
The heat utilized increases with increase in the temperature in the combustion chamber, but with decrease in the temperature of the waste gases. The rate of increase of flue-gas temperatures with increase of load on a boiler is greater than the rate of increase of the load.

Great caution is called for in measuring the temperatures of gases surrounded by bodies at different temperature, on account of radiation effects. For example, if a pyrometer or thermometer is placed between the tubes of a boiler, it will read low. *Kreisinger* and *Barkley* state that there is ordinarily an error of from 5 to 25% in temperature readings of a stream of hot gases surrounded by colder or hotter surfaces. Radiation is the chief cause of the error, and the most difficult to overcome. If a temperature measuring instrument is immersed in hot gases surrounded by cooler surfaces, it absorbs heat by convection, and its temperature rises. Gases are permeable to radiation and as soon as the temperature of the instrument exceeds that of the surrounding surfaces, heat passes from it to them through the gases by radiation. The temperature of the instrument continues to rise with a decreasing rate until the quantity of heat it gives off by radiation is equal to the quantity it receives by convection. The temperature then remains constant, but is below the temperature of the gases. The magnitude of the error depends mainly on

1. The size of the part of the instrument exposed to the gases and the radiation,

2. The difference between the temperature of the gases and that of the surrounding surfaces.

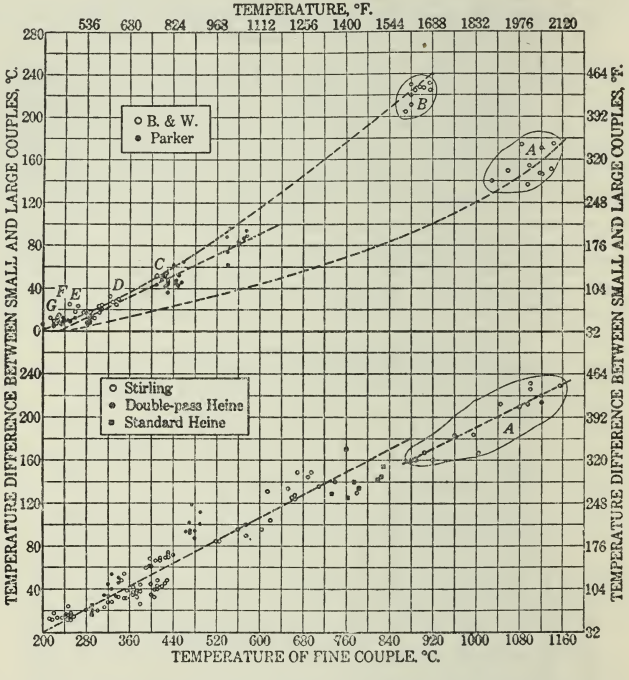
The smaller the exposed part and the smaller the difference of temperature, the smaller the radiation error. Of all temperature measuring instruments, the thermocouple can most easily be reduced in size. It can be made so small that the radiation error is negligible for practical purposes, the assumption being that a couple having an exposed hot junction made of wires of zero diameter, would indicate the correct temperature. The curve below indicates the effect of the size of the thermocouple on the temperature reading. *A*, *B*, *C*, etc., represent locations in a B. & W. boiler setting at the Carnegie Technical School. The large couple was .5 in. in diameter, and the small couple .008 in. in diameter. The dotted curve represents the true temperature of the gases as computed for a curve having zero diameter wires. The dash curve at the bottom gives the approximate velocity of the gases. The boiler was gas-fired, and the volume of gases is computed from the volume of gas burned, the chemical analysis of the products of combustion and flue temperature of the gases. The small black circle at the top left-hand corner represents the furnace temperature as observed with a Wanner Optical Pyrometer, sighted through one of the gas burners. The small couple indicates temperatures much closer than does the large one. At position *B* the large couple showed a radiation error of 575 degs. F.,



TEMPERATURE READINGS AS AFFECTED BY SIZE OF THERMOCOUPLE

The heavy curve connects readings obtained with a couple 0.5 in. in diameter and the light curve readings obtained with a couple 0.008 in. in diameter. Dotted curve is estimated true temperature of gases. Curve drawn in dashes shows approximate velocity of gases.

whereas the small one showed a radiation error of 150 degs. In position *F* where the temperature of the gases is much lower, the large couple read about 25° F. low, while the small couple showed an error of only 5° F. low. For flue gases, therefore, the small couple would be satisfactory.



EFFECT OF TEMPERATURE OF GASES ON RADIATION ERROR IN VARIOUS TYPES OF BOILERS

The above figure shows how much lower large couples read than do small ones when placed in actual boiler settings on common types of water-tube boilers. With the exception of the group marked *A*, all readings were obtained with a thermocouple placed among the tubes, *i. e.*, in places totally exposed to the heating surface of the boilers. Group *A* for the B. & W. boiler was taken with couples placed below the boiler tubes in the combustion space. The couples were partly exposed to the tubes, and partly to the brick wall, which latter were hotter than the tubes. The couples therefore did not have as large a radiation as if they had been completely surrounded by the boiler tubes. Group *A* for the Stirling boiler was taken with couples placed one foot above the arch, and one foot from the front nest of tubes. The couples were therefore partly exposed to hot brick-work, and therefore their radiation is smaller than if completely surrounded by cooler tubes.

From experiments on four different sized couples, *Kreisinger* and *Barkley* state that as the diameter of the hot junction of the couple decreases, the temperature indicated by the couple rises, at first very slowly, but after the diameter of about 1-10 inch is passed, this rise in temperature becomes very rapid, and also the greater the difference between the temperature of gases and that of the surrounding surfaces the quicker the rise. It is possible to plot a curve showing the relation between diameter of couple and temperature indicated, and from this arrive at the true temperature which would be indicated by a zero diameter couple. It is also possible to compute this curve mathematically. By placing the thermometer within a hood of a non-conducting material through which the gases circulate, the radiation error can be reduced to a negligible quantity, but the method does not necessarily give the average temperature of the flue gases, because of their possible stratification. The true temperature of gases in different parts of a section of the uptake may vary over a considerable range. The most accurate method appears to be the use of a number of thermocouples of very small wires, each of which may be shielded by a non-conducting hood screening it from hotter or colder surfaces. The *Bureau of Mines* has used a sort of crowfoot collector (see page 145) which brings gases from several points in the flue to one point where a small-wire thermocouple is placed.

An example of the error from placing the bulb of a mercury thermometer among the tubes of a boiler was found in a Pittsburgh plant, where the engineer showed a series of results giving the steam pressure as 162 lb., flue-gas temperature as 386° F. and efficiency as 78%. The temperature corresponding to 162 lb. is 371°. Apparently the flue gas was only 15° hotter than the water in the boiler. It was found that the thermometer had been inserted among the tubes of the third pass of a B. & W. boiler, and really measured the temperature of the surrounding tubes. The actual temperature of the gases was probably 200° or 300° higher.

Another instance of low flue-gas temperature readings was found in a test of a Stirling boiler at the Williston plant of the U. S. Reclamation Service. The thermometer was inserted through a door in the rear of the setting, about 3 ft. below the damper. The distance from the door to the rear steam drum was 18 in. The thermometer therefore radiated to the door, the drum and the damper, as well as to a set of pre-heating air tubes just below the thermometer. The temperature of the pre-heater tubes was probably 150° F., that of the steam drum 352°, that of the rear door about 100°, and the temperature of the damper probably 500°. A second thermometer placed in the stack about 4 ft. above the damper indicated a temperature about 100° higher than the thermometer in the uptake. The *Bureau of Mines* therefore used the funnel or crow's foot apparatus for collecting average gas samples, mentioned above. Gas temperatures taken in this were fairly correct.

Often great care is taken to calibrate a flue-gas thermometer and then it is placed carelessly in the uptake or boiler setting. The correct measurement of gas temperatures is really a high art.

ANALYSIS OF GASES OF COMBUSTION

The flue gas analysis is the means for studying and obtaining the proper combustion conditions and for determining the amount and distribution of some of the heat losses in boiler operation. For most purposes it is necessary only to take the % CO_2. This should be taken very frequently (as often as once a minute) while the conditions are being changed.

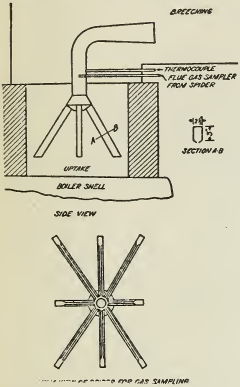
The following are the things to be studied and adjusted:

1. The firing and handling of the fire.
    - (*a*) Selection of proper firing method for the coal in use, (coking or spreading methods).
    - (*b*) The proper leveling of the fire to keep it free from air holes.
    - (*c*) The proper depth of fire.
2. The draft for the thickness of the fire and the load.
3. The setting, which should be free from cracks.
4. The secondary air supply, which must be provided to complete combustion.
5. The furnace construction.

The quantities usually determined in a flue gas analysis are the relative proportions by volume of CO_2, O_2 and CO. The free H_2 is sometimes determined where more accurate results are desired, but unless the CO is over 0.5%, determination of H_2 is useless. The analysis gives the % by volume. To obtain the % of the constituents by weight, multiply the % volume by either the density or the molecular weight, and divide each product by the sum of all the products. The even values of the molecular weights are: $H_2 = 2$, $CO_2 = 44$, $CO = 28$, $O_2 = 32$, $N_2 = 28$.

SAMPLING OF GASES OF COMBUSTION

In order for the gas analysis to have any value, the sample on which it is based must be as nearly an average as it is possible to obtain. There seems to be some diversity of opinion as to the best method of taking the sample. For sampling furnace gases the *Bureau of Mines* recommends a water-cooled tube or a quartz tube as preferable to a plain metal tube. An open ended tube placed in the center of the stream of gases gives with water-tube boilers results within 0.5% of the average composition, if the setting is fairly tight. For more exact work the sampler tube may terminate at the middle of a 1-in. iron pipe reaching across the up-take or smoke box, closed at the ends and drilled on opposite sides with $\frac{1}{16}$ in. holes 6 in. apart. A "spider," by means of which a larger volume of gases is brought together at one point and the sample drawn therefrom, is shown on page 145. The *A. S. M. E. Test Code* recommends a plain perforated ¼-in. gas pipe. *Hays* gives the following reasons why the ordinary perforated sampling pipe should not be used: 1st. Gas will flow fastest along the lines of least resistance. The nearest hole will furnish more gas than the next one and so on down the line. The chances are that the bulk of the gas, if not all of it, will be drawn through the first hole. 2d. Some of the small holes in the perforated pipe are quite certain to be stopped with soot accumulations and one would have no means of knowing when such stoppage had occurred nor which holes had been affected. 3d. The velocity of the gas flow decreases from the center of the boiler pass toward the sides, so that even if it were possible to secure uniformity of gas flow through all of the perforations in the tube, the sample derived would not be an average one. Assuming such uniformity of flow, the hole drawing from the slow-moving gas current would supply as much gas as the one drawing from the fast-moving gases. This would make the "average" secured a false one and as the gases near the sides of the boiler carry more of an air excess than those at the center, the sample would be rendered still more misleading. 4th. There is no value to taking a cross-sectional sample from side to side of the boiler pass unless you add to this sample another cross-sectional one extending longitudinally with the boiler from baffle to baffle. If there is any merit at all in the perforated pipe there should be at least one opening for every sq. ft. of space throughout a horizontal cross-section of the entire pass of the boiler.



SPIDER FOR SAMPLING FLUE GAS

The use to be made of a gas analysis determines the location of the sampling tube. In the above discussion, the total heat losses are the desired data. Therefore the sample should include all the air leakage into the setting. If the information is to be used in controlling the fire, the gas samples should be taken at some point before they are diluted by leakage through the setting. The following figures from tests by the *Bureau of Mines* show that this leakage is considerable, even in a well-maintained setting:

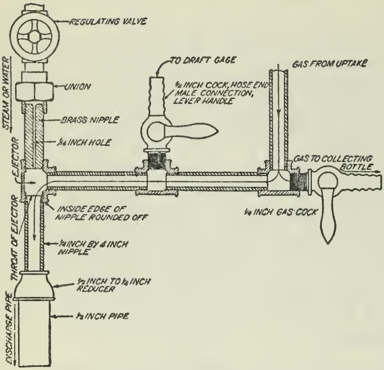
	CO_2	O_2	CO	CH_4	Sum.
Rear of combustion chamber, av..........	14.5	3.3	0	0	17.8
Base of stack, av........................	10.7	8.1	0	0	18.8

An average of 32 tests showed that the weight of gases per lb. of fuel increased 22.4% between the end of the combustion chamber and the stack.

Hays recommends taking flue gas samples at the point where the gases leave the heating surfaces of the boiler, in order to catch all of the air leakage that is really affecting efficiency. Remember the boiler damper in placing the sampling tube, so that the tube is not placed in a gas pocket. Particular attention must be paid to preventing air leakage around the sampling pipe which might give a false indication of the composition of the gases. In a B. & W. boiler the sampling pipes can be thrust through the top blow-hole at the last pass. In a Heine boiler the pipes can be run through one of the hollow stay bolts. In a return tubular boiler the top handle can be removed from the boiler doors. Place the tube six inches from the boiler head and above the top row of tubes. If it is put in too far, it may come into a dead space. Be sure to get none of the air leaking around the doors. If air leaks in at the rear arch, most of it will find its way through the upper tubes.

Hays also recommends in taking gas samples from the first pass to be sure that the fire is in good condition. If the opening of the sampling tube is immediately above an air hole, low CO_2 will be reported, whereas the actual average from the furnace may be high.

The *Bureau of Mines* states that it is advisable to connect the gas sampler to a water aspirator, so that a continuous stream of gases is maintained through the connection. A tee in the line on the upstream side of the aspirator permits a sample to be taken off by the collector or by the analyzing



DETAILS OF ASPIRATOR AND CONNECTIONS

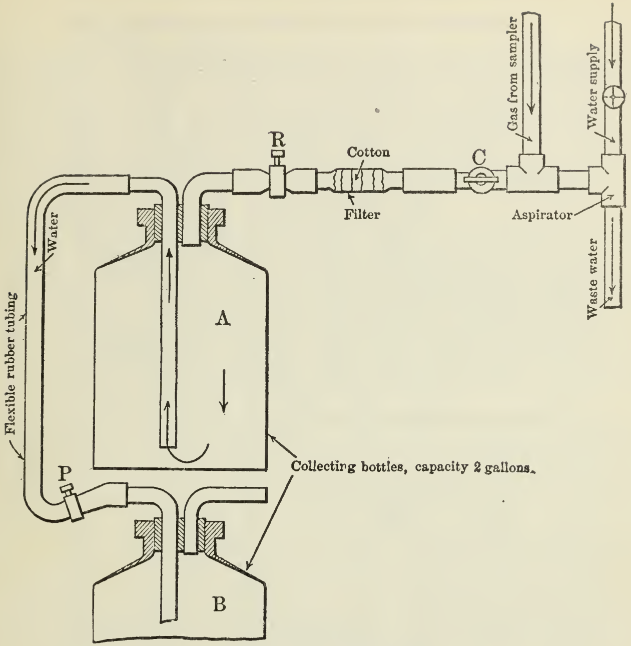
apparatus. Such an aspirator can be constructed of pipe fittings, or a simple aspirator can be purchased. An aspirator or ejector constructed from pipe fittings is illustrated. There should be no pockets in the gas line which would fill up from the condensed water vapor always contained in flue gases. Where a sample is to be taken immediately into the Orsat, an open-ended tube should be used. This should be as small as practicable, in order that the volume of air may be as small as possible, and quickly drawn out. Ordinarily filling the burette two or three times suffices to remove the air. If only CO_2 is to be determined, a $\frac{3}{16}$ or ¼-in. copper tube is a good sampler. A ¼-in. copper tube will hold approximately 1 cu. in. of gas for every 3 ft. of length. The capacity of a ¼-in. standard iron pipe is about 1 cu. in. for every 10 ins. of length.

One gas sample per hour is very little better than no gas sample at all. It is not enough to indicate an average. The sample should be taken every 5 min., and a continuous sample would be better. Speed is absolutely essential in taking gas samples. Conditions may change from instant to instant. The conditions at the time of taking the sample should be recorded in order to be able to determine the meaning of the analysis.

FLUE GAS COLLECTORS

Where it is impossible to obtain analyses directly from the boiler every few minutes, and it is desired to secure an average sample over a given period a collector can be used. A form suggested by the *Bureau of Mines* and consisting of two water bottles is shown opposite. It is connected through a gas filter to the aspirator. The water from the upper bottle is syphoned into the lower one, drawing the gas into the upper. For collecting samples over a period of half a day, bottles of 2 gal. capacity are advisable. It is suggested that all rubber connections be made of ¼-in. black seamless unvulcanized rubber tubing, of heavy walls. This tubing remains elastic, and retains gastight joints.

The *Bureau of Mines* points out that carbon dioxide is much more soluble in water than oxygen or nitrogen, their respective solubilities being approximately 90, 2 and 1. Furthermore, water from well or river is usually more nearly saturated with oxygen or nitrogen than with carbon dioxide. It is therefore easily seen that the collection of gas over water may indicate an entirely incorrect % of CO_2. If the analysis of the gases in question were always the same, the water would become saturated with CO_2, and would neither give up nor absorb CO_2. Experiments show that a brine solution will absorb CO_2 less readily than will water. A 10% solution is effective, but a saturated solution is better. This saturated solution is made up of about 3.5 pounds salt to 10 pounds water. If the % of CO_2 does not vary more

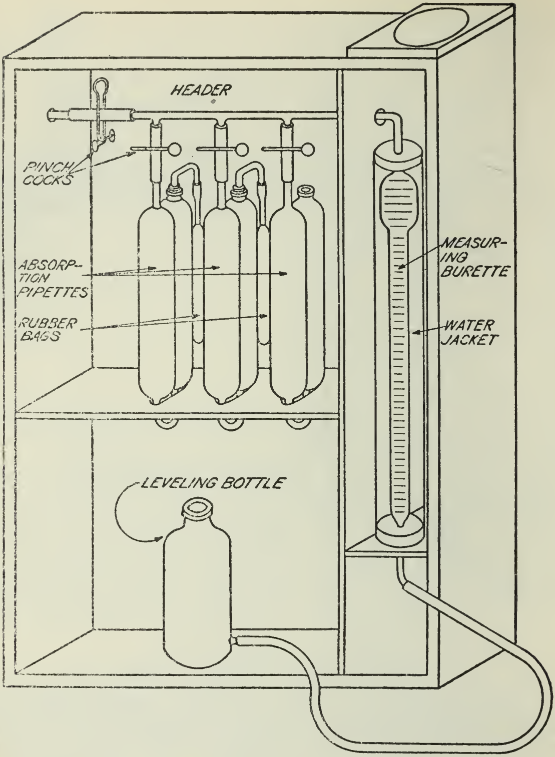


FLUE GAS COLLECTOR

than 2 or 3%, and if the gas does nor stand over the liquid more than 2 hr., water may be used satisfactorily for the confining liquid. Brine may be used to advantage for gases that have a greater variation than 3% of CO_2, and that are held more than 2 hr. over the liquid. Flue gas should be analyzed as soon as collected. Shaking of the liquid, and any change in the temperatures should be avoided. Ordinarily when collecting flue gases in the boiler room, it is doubtful whether the % of CO_2 of the collected gas when analyzed is closer than ½% to the gas as it enters the collection bottle. It should also be noted that with the ordinary arrangement the gas is drawn into the sampling bottle uniformly with respect to time and not in proportion to the load. If the load varies much, such samples are of little value.

FLUE GAS ANALYZING APPPARATUS

There are several types of apparatus for analyzing flue gas. The Orsat, which is representative and most widely used, will be described. The accompanying diagram and description are due to the *Bureau of Mines*. The essential parts of the apparatus are a measuring burette, three absorption pipettes, a leveling bottle and a header, all of glass. The measuring burette ordinarily contains 100 c.c., and is graduated in 100 units, each unit being graduated into fifths. It is usually enclosed in a water jacket, which prevents sudden temperature changes while the analysis is being made. The pipettes are U-shaped glass vessels, and contain solutions for absorbing the gas con-



ORSAT APPARATUS

stituents. The first one contains caustic potash solution for absorbing the CO_2. The second one contains an alkaline solution of pyrogallic acid for absorbing oxygen, while the third contains an ammoniacal solution of cuprous chloride, for absorbing the carbon monoxide. The side of the pipette in which the absorption is to take place is filled with small glass tubes, which increases the surface of liquid in contact with the gas. The pyrogallic acid solution and the cuprous chloride solution absorb oxygen readily. Air must be kept from coming in contact with them. A rubber bag is placed on the rear side of both these pipettes, or a water-seal consisting of a fourth pipette is used. The gas is drawn into the burette and forced out of it by means of a leveling bottle attached to the lower end of the burette by a 3 ft. rubber tube. The leveling bottle also permits regulation of the pressure on the gas. The header connecting the burette and the pipette is made of ¼-in. glass tubing. Each outlet is sometimes fitted with a ground glass cock, but such cocks require constant attention to prevent them from sticking and leaking. Pinch-cocks on the rubber tubing are as satisfactory.

PREPARATION OF SOLUTIONS

The solution for CO_2 absorption is caustic potash, or potassium hydroxide, KOH. The solution should contain 330 grams of potassium hydroxide for 1000 c.c. of water. This is about 14 oz. dissolved in 61 cu. in. of water, or 1 lb. of caustic to 2.5 lb. (2½ pints) of water. It can be made in an open vessel, and when cool poured into a bottle for storage. If a precipitate forms, which is usually the case, only the clear liquid should be used. This solution will fill a pipette about 5 times, and each pipetteful can be used for about 150 determinations.

For absorbing oxygen, the solution is prepared by dissolving 10 grams (about ⅓ of an ounce, or 2½ cu. in.) of pyrogallic acid in 25 c.c. (about 1 fluid ounce, or 2 cu. in.) of water. This is poured into the pipette, and potassium hydroxide solution from the caustic stock bottle added until both arms of the pipette are a little more than half full. The two solutions should be mixed in the pipette and the seals attached immediately in order to prevent oxygen absorption from the air. The mixing is done by raising and lowering the leveling bottle a few times, which draws the gas. Light causes a deterioration of this solution.

The solution for absorbing CO can be prepared best in a two-quart bottle. To 750 cu. cm. (about 25 fluid ounces, or 46 cu. in.) of water in the bottle is added 250 grams (about 9 ounces, or 30 cu. in.) of ammonium chloride. The mixture is shaken until the crystals are dissolved, which is accomplished quite readily. To this solution is added 200 grams (about 7 ounces, or 12 cu. ins.) of cuprous chloride. The chloride dissolves slowly, and the mixture should be shaken from time to time. All of the cuprous chloride may not dissolve. When the solution is being used, only the liquid should be poured off, without disturbing the sediment. A few pieces of scrap copper should be placed in the stock bottle to keep the cuprous chloride reduced. If tightly stoppered, the solution can be stored indefinitely. In preparing the solution for the pipette, pour out enough into a graduated vessel to fill one arm of the pipette. To this quantity add slowly ammonium hydroxide having a specific gravity of .91. As the ammonia is first added, a white flaky precipitate forms, which disappears as the addition of ammonia continues, and the solution becomes dark blue. The mixture should be stirred well while the ammonia is being added, and the amount of ammonia should be just enough to dissolve the precipitate completely. The ratio of stock solution to ammonia is about 3 to 1. If too much ammonia is added, the vapor will increase the volume of the gas sample after contact with the solution. When new, this will dissolve all the carbon monoxide from the gas, provided sufficient time is allowed, but after it has absorbed considerable carbon monoxide, it will not remove it all from a gas mixture, and may even give some off. The operator must therefore know the condition of the solution, to be certain of his results. For small amounts of carbon monoxide, a solution that has not previously absorbed much can be used.

According to *J. E. Terman,* the absorption capacities of Orsat solutions are as follows:

Potassium hydroxide 40 times its own volume before it becomes too weak.

Potassium pyro-gallate, 2 times its own volume.

Cuprous chloride, its own volume of CO. Some authorities give higher values, but this solution is cheap, and is not very good at the best.

MANIPULATION OF ORSAT APPARATUS

Black rubber tubing should be used, it is more elastic and will maintain a gas-tight joint better than other tubes.

The pipettes should be removed from the rack for filling. The solution should fill the arms a little more than half full, and when drawn up to the thin mark on the stem of the pipette, it should stand in the rear arm to a depth of about one inch. Care should be taken not to get the solutions on the hands or clothing, as they are strongly alkaline.

There are several points which should be followed in the care and use of the Orsat. Where ground glass cocks are used, they should be well lubricated with vaseline in thin films, so that they are gas tight and will not corrode. The water in the burette and leveling bottle should be saturated with flue gas. If any of the solutions are accidentally drawn into the burette, the water should be changed. The apparatus should be kept clean. The rubber connections should be watched carefully to see that they are gas-tight, and tests for leaks should be made every day before an analysis is done. All measurements of volume must be made under the same pressure. This is accomplished by means of the leveling bottle. Changes in temperature during the analysis should be avoided, as they introduce error.

The apparatus should be tested for air leakage. To do this, the burette is filled about half full with air, and all the stop-cocks closed. The leveling bottle is lowered two or three feet, the air inside being thus placed under a reduced pressure. If the water in the burette falls to a certain point and then remains stationary, there is no leak, but if it continues to fall slowly, there is a leak, which must be stopped before the analysis is undertaken.

The manipulation of the Orsat apparatus consists of two operations, moving the gases into the different parts of the Orsat, and measuring their volumes. The moving of the gases is done with the water in the leveling bottle, which acts as a piston. The Orsat is connected to a source of gas supply, such as the collector bottles, or the gas pipe to the aspirator, usually through some form of filter. By raising or lowering the leveling bottle and opening the cocks to the absorption pipettes in turn, the level can be adjusted to the mark on the neck of the pipette. With the burette filled with water, opening the cock in the gas supply line and lowering the leveling bottle will draw a charge of gas into the Orsat. The cock in the gas supply line should then be closed and the cock to the atmosphere opened, and this quantity of gas rejected to the atmosphere by raising the leveling bottle. This should be done two or three times to remove all the air and residual gas from the Orsat apparatus, after which a charge is retained for analysis. A delicate means of adjusting the flow of water from the bottle is to pinch the rubber tubing in the hand. The quantity of gas is accurately measured to 100 c.c., by adjusting the level in the leveling bottle and in the burette to the zero mark on the graduation, releasing some of the gas from the system. It is essential in all volume measurements that the level in the burette and in the leveling bottle be the same.

The cock in the caustic potash pipette is opened and the leveling bottle raised, forcing all of the gas into the pipette until the water level stands in the neck of the burette. The gas is passed between the burette and the pipette two or three times, and then measured. It should then be passed into the pipette and again into the burette and remeasured in order to be sure the CO_2 has been entirely absorbed. The difference in volumes before and after absorption is the amount of CO_2 in the sample, and as the sample was originally exactly 100 c.c., it is the % CO_2 in the gas. The oxygen and the carbon monoxide are determined in the same way by passing the residual gas successively into the remaining pipettes. After any one of the absorptions, before the measurement, the solution must be brought to the neck of the pipette.

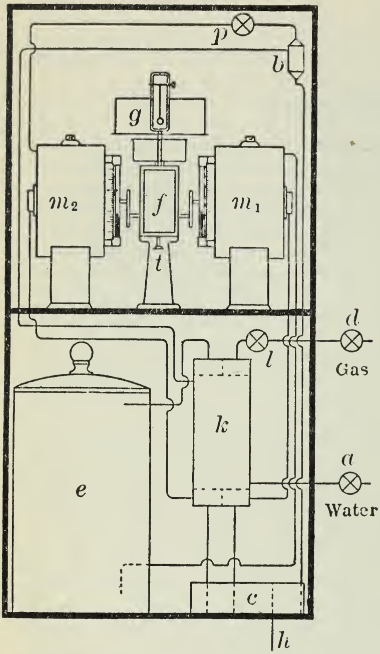
CO_2 RECORDERS

While hand indicators, such as the Orsat, can be used as a means of studying air-supply conditions, or for occasional tests, they do not answer the purposes of daily plant operation, since the CO_2 content of the flue gases may, and does, vary widely, rapidly and continuously, due to the fact that the proportions of the total air supply which come through the fire and in above the fire are easily upset by the throwing on of fresh coal, the burning through of thin spots, accumulations of clinker and ash, manipulation of dampers and fire-doors, etc. It can hardly be said that CO_2 recorders act promptly enough to follow the variations in CO_2 from minute to minute, but they do on the other hand, produce a chart showing an average, which serves as a warning to the fireman who is careless or incompetent in his management of the fire and draft. Wherever possible, it is advisable to so arrange CO_2 machines that the gases will be drawn rapidly and in a constant stream from the furnace to a point near the CO_2 machine, and in excess of the requirements of the latter. In this way, lag in the indications of the machine, due to storage in the pipe line and filter, can largely be overcome. A filter should be installed near the point of sampling. Directions in regard to the location and arrangement of sampling pipes, as given on preceding pages, also apply here.

In 1916 the *Bureau of Mines* made laboratory and service tests of instruments on the market at that time for recording carbon dioxide in flue gases, determining (1) the lag in recording changes in composition of the flowing gas, (2) the accuracy of each type of recorder, (3) the variable factors affecting the operation and accuracy of each type, (4) the repairs and renewals necessary, and (5) the kind and amount of attention required. The first three tests were of a laboratory nature, whereas the information relating to the fourth and fifth items was obtained by operating the instrument for a period of several months under conditions practically as they would be found in a commercial steam power plant having only a day load. All of the machines tested only for CO_2, oxygen and CO being neglected.

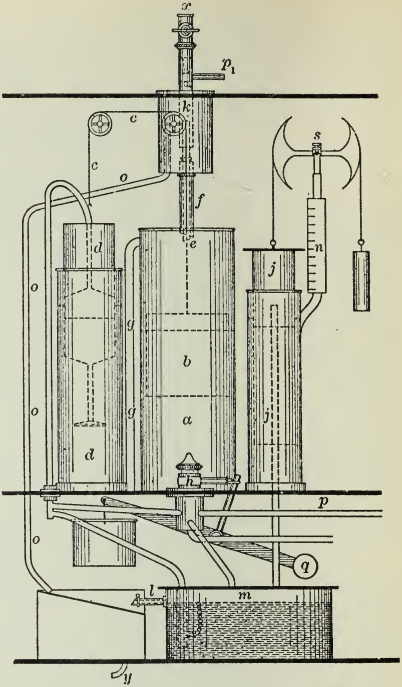
Two of the instruments tested may be described as automatic Orsat machines, some motive power, such as flowing water, serving to pass a sample of gas through an absorbing medium, and to measure the volume and record the loss in volume. Two others may be described as continuous meters, in that gas is drawn continuously through the absorbing medium, and its volume measured before and after absorption of the CO_2, in the one case, by means of small displacement meters, and in the other by means of orifices and pressure differential manometers. A third kind of instrument passed a sample of atmospheric air and a sample of flue gas through two small fans whirled at constant speed by an electric motor, and measured the difference between the pressures produced by the two fans, as an indication of the difference in density and therefore of the CO_2 content of the flue gases. The characteristics of these several recorders, as noted by the *Bureau of Mines*, are as follows:

In the *Bimeter CO_2 Recorder*, manufactured by the Cambridge Scientific Instrument Co., Cambridge, England, the gas is drawn by a water jet suction pump first through a small gas meter, using oil as the sealing means, then through the absorption chamber and finally through the second gas meter. The recording pen is actuated by means of a differential drive operated by



d	Gas Inlet
b	Suction pump
m_1	First meter
e	Absorption chamber
m_2	Second meter
g	Recorder

BIMETER CO_2 RECORDER

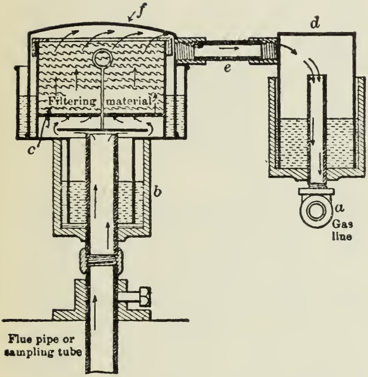


p	Gas inlet
d	First measuring bell
m	Absorption chamber
j	Second measuring bell operating the pen
n	Indicator
a	Siphoning tank

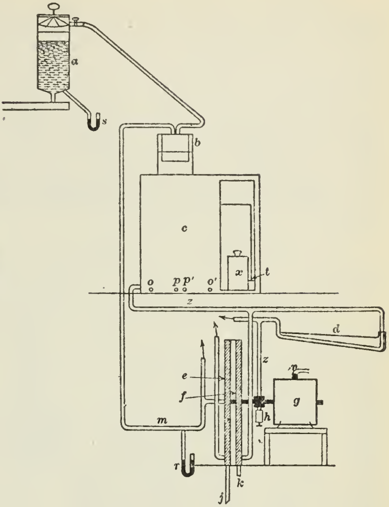
SIMMANCE-ABADY CO_2 RECORDER

the two meters. The absorbing material is slaked lime, packed in a box with excelsior. The instrument will make some 20 to 25 analyses per hr., that is, from 1/20 to 1/25 hr. is required for a sample of gas to pass through.

Evidence of a change in composition begins to show in about 5 min. after a change in the CO_2 content, but 28 min. is required to come to the nearest ½% after a change, and 38 min. to complete the record of the change. So long as the instrument is kept in proper adjustment, the maximum error for any given analysis when the instrument is operating on gas of constant composition is ± .5% CO_2, and the accuracy is not affected by room temperature, boiler draft or number of records per hour. The absorbing material is sufficient for from 555 to 1194 percent-hours, the percent-hour being defined as 1% of CO_2 for 1 hr., but as there is no convenient means of determining whether the reagent is still active, except by a check analysis, it is necessary to recharge for the minimum period. The operation of recharging occupies 30 to 45 min.



DUST FILTER AND CONNECTIONS, SIMMANCE-ABADY CO_2 RECORDER



a Gas filter and inlet
m Gas flow
e Gas fan
h Air inlet
f Air fan
b Differential jars
x Recording chart

"TELEZOMETER" CO_2 RECORDER

The *Simmance-Abady CO_2 Recorder*, made by the Precision Instrument Co. of Detroit, is a true Orsat, a measured sample of gas being drawn, passed through the absorbing material, in this case a solution of KOH, and then measured under a bell, the rise of the bell being recorded each time. This machine will make 16 to 17 records per hr., with an accuracy of ± .1% to ± .2% when the composition of the gas is not changing. It has a lag of 23 min. for an indication to come to the nearest .5%, and 34 min. to complete the record of a change in the composition of the gas. The charge of reagent is sufficient for about 5100 percent-hours, and the time required to change the reagent is 15 min. The accuracy of the instrument is affected somewhat by changes of room temperature and draft, and by the number of records per hour.

The *Telezometer CO_2 Recorder*, marketed by Herman Bacharach, Pittsburgh, consists essentially of two small fans driven at constant speed by an electric motor, combined with a balance which measures the difference in the pressure differentials produced by the two fans. No absorbing medium is required. With gas of constant composition, the accuracy is about ± .2%, and when a change is made to a gas of lower CO_2 content, the lag for the analysis to reach the nearest 1% is about 5 min., and to reach the nearest ½% about 30 min., while about 34 min. is required for a completed record. Evidence of a change in composition begins to show practically at once. When the CO_2 content is increased, there is a lag of about 6 min. to reach the nearest ½%, and of about 8 min. to complete the record.

The *Sarco Automatic Combustion Recorder*, made by the Sarco Engineering Co., New York, may also be described as an automatic Orsat, differing from the preceding, however, in that the only moving parts except the clock are the two inverted bells which measure the gases, all other functions being performed by syphoning arrangements. The absorbing material is a solution of KOH, having a life of 2260 to 2490 percent-hours and requiring about 5 min. for changing. The accuracy with constant gas composition was ± .4%, and about 9 min. were required for the indication to come to the nearest .5%, and 12 min. for a completed record of a change. These figures, however, do not include the time for changing the gas in the supply line, whereas those given for the preceding two instruments do. 30 analyses per hr. is suggested as the proper rate of operation.

In the *Uehling CO_2 Machine*, made by the Uehling Instrument Co., Passaic, N. J., a constant stream of gas is drawn through two orifices in series, between which is placed the absorbing material.

The vacuums before the first orifice and after the second are maintained constant. The vacuum between the orifices then measures the % of CO_2. If, for example, all the gas were CO_2, there would be no flow through the second orifice, and the vacuum beyond the second orifice would obtain between the two orifices. If on the other hand, none of the gas were absorbed, the vacuums between the two orifices would be fixed by their relative proportions. Pipes connecting with the space between the orifices communicate with pressure indicating gauges on the side of the instrument and on the boiler front, and with a recording instrument, which can be placed wherever desired. The lag of this machine is about 5 to 8 min. for an indication to the nearest 5%, except when gas containing no CO_2 is admitted to the sampling tube. The time required for a complete record of a change is 6 min. for a change from 6.8 to 5.2% CO_2, 17 min. for a change from 0 to 6% CO_2, and 70 min. for a change from 7% to 0 CO_2. The maximum error when operating on a gas of constant composition is ± .1%. The accuracy was affected slightly by change of room temperature, but not by change of boiler draft. The absorbing reagent is sodium hydroxide (NaOH) packed in pasteboard cartons that fit in a case on the instrument. The material lasts from 500 to 1185 percent-hours, and the degree of exhaustion can be ascertained by locating with the hand the location of the hottest zone on the carton case. The time required for recharging is 8 or 10 min.

The *Bureau of Mines* draws the following general conclusions from the tests:

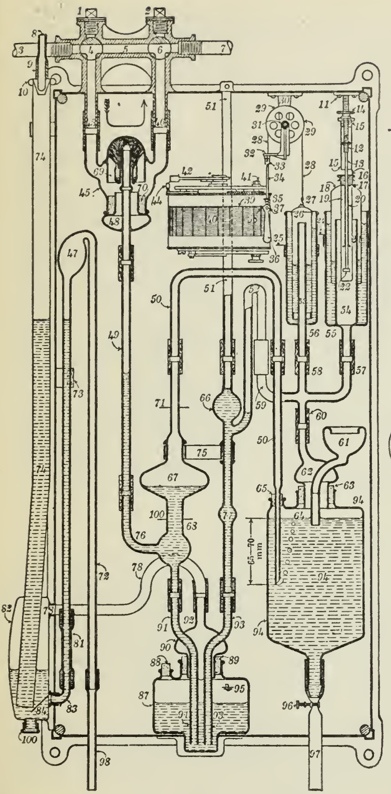
1. Evidence of a change of composition in gas is shown soon after the change takes place, the maximum time for such evidence to show being 8 min. The correct registration within ½% requires a longer time, according to the type of machine. The lag of the system is that of the instrument, plus that due to the piping to the boiler, the latter depending on the length and diameter of the pipe used and the rate at which gases are drawn through it.

2. When properly set up, and so long as the instrument remains in adjustment, the error of the record when the composition of the gas is not changing, varies between .1% and .5%, according to the instrument.

3. Changes in the temperature of the surrounding air, in the boiler draft and in the speed of the instrument cause an appreciable error in some types.

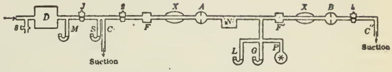
4. The life of a single charge of the alkaline reagent used varies from 500 to 5,100 percent-hours.

5. The ordinary daily attention required to wind the clock, change the charts and ink the pen, amounts to 5 to 15 min. of the fireman's time. Adjust-

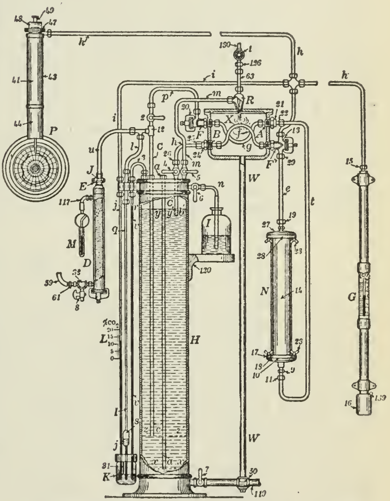


3 Gas inlet
8 Water inlet
49, 67, 50 Path of gas
94 Absorption chamber
18 and *26* Measuring floats
40 Recording chart

SARCO AUTOMATIC COMBUSTION RECORDER



Essential Parts Arranged as a Train



D Gas filter
A and *B* Orifices
X and *X* Constant temperature steampots
N Absorption carton
L CO_2 Indicator
G Distant indicator
P Recording chart

UEHLING CO_2 MACHINE

ments and the changing of the reagents, and any special care, should be left to the engineer or someone else who thoroughly understands the instrument. The time required for changing reagents varies from 5 to 45 min., according to type of instrument.

6. The expense of maintenance, not taking into account the time required for adjustments, was confined practically to the cost of the reagent.

The *Bureau* points out that it is necessary, with each instrument, for someone in charge to become entirely familiar with its principle and manipulation. Things which may interfere with proper operation are usually easily remedied, but are not always evident on casual inspection. The character of the instrument, moreover, is such that it should be placed in the charge of someone who is qualified to handle delicate instruments.

It is recommended that the sampling pipe and gas line of any CO_2 recorder should be of ¾-in. pipe. A satisfactory way of arranging the pipe is to drill the end inserted into the boiler pass with small holes ⅛ to $\frac{3}{16}$ in. in diameter every few inches in a line on one side of the pipe. The pipe is placed clear across the pass, in a convenient point in the gas travel, the small holes in the pipe being at right angles to the flow. The sampling pipe should be at a place where the flue gases become well mixed, as near the damper on the boiler side, sluggish pockets of gas being avoided. All turns in the gas line should be made with crosses instead of elbows, the extra openings of the crosses being plugged. This allows the line to be easily cleaned. In running a gas line from the boiler to the filter and from the filter to the instrument proper, great care must be taken to insure a tight line, so that the gas cannot become mixed with outside air. Asphaltum paint should be used in the joints, and it should be applied to the entire line after it is connected. There should be a slight fall of the line toward the recorder, and sagging pockets should be avoided. Just in front of the instrument, a vertical drop pipe should cross the pipe line and a small drain trap should be placed at the end of the drop pipe. Water can then accumulate in the drop pipe, and be let out from time to time. The entire line should be so arranged that it can be blown out, preferably by compressed air, or by steam. Each of the recorders has a manometer arrangement to show when the line becomes clogged to such an extent that blowing out is necessary.

WHAT CO_2 INDICATES

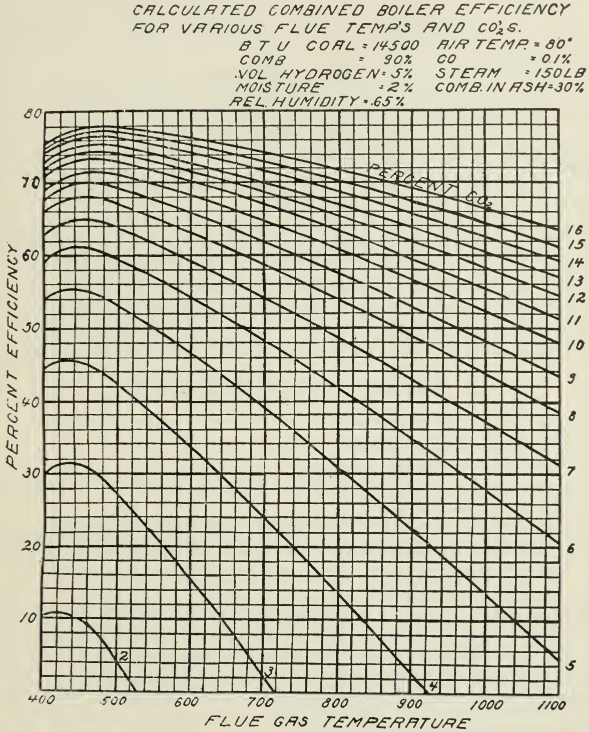
The CO_2 indication answers most practical purposes. If greater certainty or refinement is desired after the CO_2 has been brought up to the required percent, the CO determination can be made. As pointed out by *Steam*, while high CO_2 indicates a small amount of excess air, it does not necessarily mean a correspondingly good combustion. 1% of CO in the flue gas would be a negligible indication of the quantity of excess air, but might mean 4½% loss due to incomplete combustion.

Low CO_2 may be caused by excess air, insufficient air (high CO) or improper mixture of the air and gases, but a surplus of air is the cause in almost every instance. The difference between the CO_2 percentages in the last and the first passes indicates the air leakage in the setting.

CO_2 is also affected by the character of the fuel. The more hydrogen in the fuel, the less CO_2 in the flue gases. If the fuel were all carbon, there would be 21% CO_2. If all hydrogen, there would be no CO_2 in the gases.

Hays warns against attempting to secure high CO_2 by cutting down the draft only. High CO_2 can be obtained, he says, with any draft in reason, either high or low, provided the draft and the fuel resistance are in proper relation. CO_2 percentage indicates the ratio of the air used to the air that has not been used. It is sometimes feared that 8 or 10% CO_2 cannot be obtained without CO in considerable quantities. This is not in accordance with his experience. He does not consider that there is danger from CO until about 15% CO_2 is reached. It is assumed for the above statements that the setting is right, and that there is sufficient draft. *Bureau of Mines* tests, on the other hand, show considerable percentages of CO with CO_2 running from 8 to 10%; in fact it is said to be difficult to average 12% CO_2 in hand-fired boilers without getting CO.

The chart below, by Haylett O'Neill, gives the net overall boiler and furnace efficiencies for various flue gas temperatures and CO_2 for a given coal. While given only as an approximation, it serves to illustrate the point.



RELATION OF BOILER EFFICIENCY, % CO_2 AND FLUE GAS TEMPERATURE

Due to dilution of the gases by excess air, the lower the % of CO_2, the greater will be the waste that the drop of each succeeding percent indicates. A drop from 16 to 10% CO_2 means a loss of fuel of 6%, while a drop from 10 to 6% CO_2 means 12% loss of fuel, and a drop from 6 to 2% means 57% loss of fuel.

A. Bement gives a series of curves on page 159, which shows the relation of firing to the % of CO_2. In each case % of CO_2 is plotted against time.

In Chart *a*, condition A represents a dirty fire, while condition B represents a clean fire. This is with hand firing.

Chart *b* is for a sloping grate stoker with a dump grate at the rear. CO_2 dropped when the fire was cleaned, but recovered as soon as the dump grate was closed. Poking the coal down from the hopper resulted in so much volatile being distilled off that it did not burn. The CO_2 recovered as soon as the coal had burned to normal. It had been considered that poking down the coal after cleaning was a good thing.

Chart *c* represents good practice in hand firing. The CO_2 rises to a certain point after the fresh coal is fired. It drops away gradually as the fire burns away. The second firing is better than the first, as the CO_2 is higher and continues longer.

Chart *d* represents hand firing. The fire was full of holes, admitting excess air. When the pile was leveled with the rake, the openings were closed and the CO_2 immediately built up.

Chart *e* represents the work of two different firemen in hand firing. When A added coal the CO_2 dropped slightly, because he dumped the coal with little or no care. B broke his coal properly and spread it carefully, and the CO_2 rose slightly with each firing.

Chart *f* is for a chain grate stoker. Many firemen think there is no harm in letting the coal get low in the hopper provided it does not go below the gate.

Chart *g* shows the result of letting the fire get short on a chain grate, and the recovery of CO_2 when the fireman winds up the grate.

Chart *h* indicates the advantage of being able to ascertain what has happened when accidents occur. At 3 P.M. the bridge wall failed. This was due to excessive temperature, which is indicated by the high CO_2.

WHAT CO INDICATES

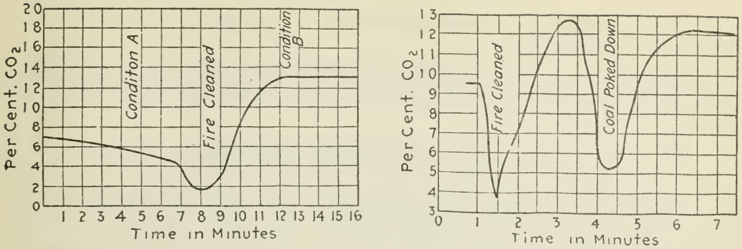
The formation of CO is due to:

1. Furnaces of poor design,
2. Improper methods of firing,
3. Character of fuel, particularly with reference to the equipment with which it is burned,
4. Improper mixing of the combustible gases with the air,
5. Low furnace temperature, so that the gases are cooled below the ignition point,
6. Deficient air supply.

The formation of CO is generally due to insufficient air supply, which, as pointed out by the *Bureau of Mines*, may be either local or general. Either the local or general cause may be from the composition of the coal. The coal may be fusible, in which case the surface of the fuel forms one solid layer of semi-liquid fuel, which effectively stops the passage of air. At the same time, a large excess of air may be fed into the furnace elsewhere. The same local excess or insufficient air supply may be caused by the fusion of ash on the grates. The volatile matter may be driven off so rapidly after a fresh charge of coal that the average air supply is not sufficient, whereas a couple of minutes after firing it is too large.

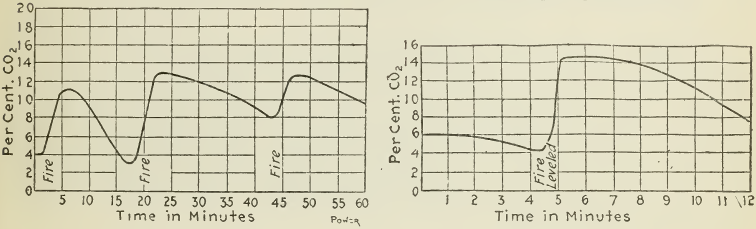
According to *A. Bement* the occurrence of CO in the waste gases is a decided danger signal, not so much on account of the loss which it represents, but because it is usually accompanied by unconsumed hydrogen and hydrocarbons. The formation of CO is a loss of small magnitude (never over 1% of the heat value of the fuel), yet as it may be determined easily, while the escaping volatile cannot be determined by any practicable means, the more or less general belief is that CO represents the entire incomplete combustion loss.

Hays says that CO may occur with any % of CO_2. Suppose that the fire is very thick, and perhaps dirty, in one portion of the furnace. This would result in CO, because the thick and dirty part would not receive enough air. Suppose that there were an air hole at another point. Excess air would



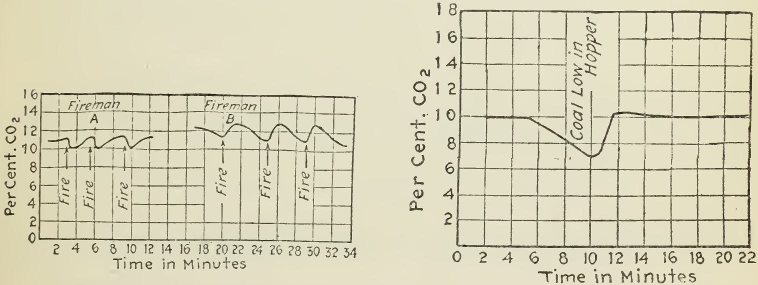
A—Dirty *vs.* clean fire, hand firing

B—Sloping grate stoker



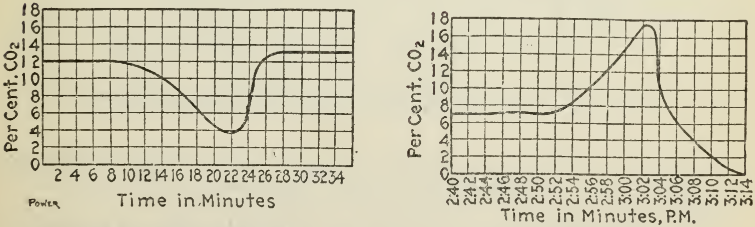
C—Good hand firing

D—Effect of leveling fire



E—Work of different firemen

F—Low coal, chain grate stoker



G—Short fire, chain grate stoker

H—Cause of accident

EFFECT OF INTERVAL AND METHOD OF FIRING ON CO_2

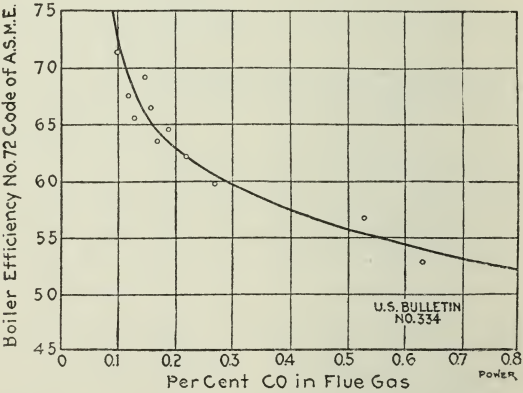
go through, and there would be CO in the flue gases in the presence of an excess of air and low CO_2.

CO occupies twice the volume of the oxygen entering into its composition. The sum of the % of CO_2, oxygen and half the % of CO should have the same ratio to the nitrogen in the flue gases as the oxygen to nitrogen in the air supplied, viz., 20.9 to 79.1.

This takes no account of the hydrogen in the fuel. Hydrogen in the volatile constituents of a fuel leads to an increase in the apparent percentage of nitrogen in the flue gas. This is due to the fact that the water vapor formed by the combustion of hydrogen condenses at the temperature of the analysis, while the nitrogen which accompanied the oxygen remains in gaseous form.

The ordinary analysis with the Orsat does not consider other combustibles than CO.

Figured on the total heat value of the fuel, .1% CO in the flue gases means .47% heat loss, .1% hydrogen in the flue gas means .48% loss, .1% CH_4 1.52% loss. In 48 tests at the St. Louis Fuel Testing Plant of the *Geological Survey*, as the CO increased from .3 to .7%, the efficiency dropped from 65 to 57%. This was a 2% drop for each .1%, or 4 times the theoretical amount. The hydrogen and methane were not determined. The conclusion was reached that at least two-thirds of the large drop in the whole boiler efficiency with the rise of CO was due to incomplete combustion losses not represented by CO, so that high CO is a decided danger signal. Other *Bureau of Mines* results are shown below.



RELATION OF AVERAGE CO TO BOILER EFFICIENCY

Sufficient CO in the gases may cause an action known as secondary combustion, the CO igniting with air in the flues or in the stack, with a resultant loss of heat and overheating of the flues and stack.

The direct heat loss due to CO in the combustion gases can be computed from the formula or obtained from the chart given under Heat Balance (page 235).

OXYGEN IN COMBUSTION GASES

The percentage of O_2 in the flue gas indicates the excess air more accurately than does the percentage of CO_2, but its determination requires more time.

AIR REQUIREMENTS AND SUPPLY

The *Bureau of Mines* states that for every combination of furnace, coal and method of firing fuel, there is some minimum value beyond which it does not pay to reduce the air supply. Very few boilers are operated dangerously close to this limiting value. The majority of them are operated with too large an excess of air.

Due to imperfect mixture of gases, if every particle is to have sufficient air for combustion, some particles will have more than the theoretical amount, but complete combustion of the coal in the boiler furnace can be obtained with not more than 40% excess air. So long as the fire bed is level only about 7 lb. of air per lb. coal can be forced through the fuel bed. A thick fuel bed is preventive of excess air only insofar as it prevents the formation of holes. When the fire is thick or dirty, only a small amount of air flows through the fuel bed and therefore the coal gasifies at a slow rate. On account of the high resistance of the fuel bed the draft in the furnace increases and draws a larger quantity of secondary air into the furnace (through the fire door, leaks, etc.) than is needed to burn the small quantity of combustible gas arising from the fuel bed. Clinkers on the grate will also reduce the rate of combustion and increase the excess of air.

Low CO_2 may be caused by fused ash on the grates, parts of the fire being turned up by the slice bar, so that the ash on top of the incandescent coal melts. The ash may melt due to the furnace temperature being too high, owing to ignition arches and tile on lower row of boiler tubes. The remedy is to expose the lower row of tubes or shorten the combustion arch. The low fusion point of ash may be due to mixture of coals.

The *Bureau of Mines* states that with high-ash coals, a high draft is required. This will necessarily increase the leakage of air through the setting, so that the flue gas analysis may show a high air excess.

Air in excess of the required amount dilutes the gases and carries heat up the stack, and irrespective of the heat loss in the dry chimney gases, excess air is likely to cause furnace losses due to incomplete combustion, on account of the lower furnace temperature.

If the analysis of the fuel is known, the weight of air required to burn 1 lb. of combustible can be computed from the formula:

$$\text{Lb. air} = 11.52C + 34.56\left(H - \frac{O}{8}\right) + 4.32S$$

C, H, O and S are fractions by weight of these elements in coal, free from moisture and ash.

The ratio of the air supplied to the air theoretically required is found by the formula:

$$R = \frac{N_2}{N_2 - 3.782\,(O_2 - \tfrac{1}{2}CO)}$$

N_2 = fraction of nitrogen in the flue gas,

O_2 = fraction of oxygen in the flue gas, and is that amount of oxygen in the air supplied which has not been utilized in combustion,

CO = fraction of carbon monoxide in the flue gas.

The gases per lb. of dry coal

$$= \frac{[11CO_2 + 8O_2 + 7\,(CO + N_2)]\,(C - C_r)}{3\,(CO_2 + CO)} \text{ lb.}$$

CO_2, O_2, CO and N_2 = fractions of constituents in flue gases by volume.

C = fraction carbon in dry coal

C_r = carbon in refuse, as fraction of dry coal burned

Since $CO_2 + O_2 + CO + N_2 = 1$, formula can be written:

Weight of gases per pound of dry coal

$$= \frac{(4CO_2 + O_2 + 7)\,(C - C_r)}{3\,(CO_2 + CO)}$$

The table on page 121 gives weights of gases per 10,000 B.T.U. for different CO_2 contents.

The ratio of excess air can be found by subtracting the air theoretically required per pound of combustible (or coal) from the air actually supplied per pound and dividing by the theoretical amount. It may also be obtained by subtracting one from the ratio of air supplied to air required.

Formulas in which no account is taken of the hydrogen in the fuel are only approximate. The combustion of the hydrogen results in water, which is condensed at the temperature of the gas sample. The amount of nitrogen shown by the flue gas analysis is therefore greater as the hydrogen in the fuel is greater, by the amount of nitrogen accompanying the oxygen in the air that is used in burning the hydrogen.

To estimate roughly the % of excess air from the % of carbon dioxide, subtract the observed % of CO_2 from 20.7, divide the remainder by the observed % of CO_2, and multiply by 100. Roughly, there is 1% of fuel lost for every 12.1% of air above 38%.

G. Herberg gives formulas for the quantity of gases of combustion which take into account the hydrogen and water in a fuel:

C = % carbon in coal actually burned (% C in coal less % C through grates),

H = % hydrogen in coal actually burned (similar to above),

W = % moisture in coal.

The foregoing percentages by weight are based on coal as fired, and together with the following percentages by volume are to be used in the formulas as *decimal fractions:*

CO_2 = % carbon dioxide in flue gases,
O_2 = % oxygen in flue gases,
CO = % carbon monoxide in flue gases,
CH_4 = % methane in flue gases,
N = % nitrogen in flue gases,
Neglect percent SO_2,
R = lb. of carbon in soot for each cu. ft. of gas,
G = cu. ft. of gas at 32° F. and atmospheric pressure.

The complete formula is:

$$G \text{ (in cu. ft.)} = \frac{29.89\ C}{CO_2 + CO + CH_4 + 29.89\ R} + \frac{9H + W}{.0509}$$

Since CH_4 and R are small and are seldom determined, the formula may be simplified to: $G = \frac{29.89C}{CO_2 + CO} + \frac{9H + W}{.0509}$

To determine the volume of flue gases at any other temperature, t° F., multiply this volume G by $\frac{460 + t}{492}$

The volume due to water and hydrogen in the coal could readily be added to the first formula giving weight of gases. See section on Stack Proportions, page 119.

In chart on page 164, redrawn from *H. O'Neill*, allowance is made for the hydrogen in the fuel. If the burning of a coal with a certain hydrogen content in the combustible results in a certain % of CO_2, the % excess air and the weight of gases from the combustion of 1 lb. of combustible can be read from the curve. The % of H in the coal must be converted into % of H in the combustible in using the curve. The air per lb. of combustible is then converted to air per lb. of coal by multiplying it by the fraction of combustible in the coal.

From analyses of the furnace and flue gases, the *Bureau of Mines* has computed the following figures showing the average weight of gases per lb. of carbon at different points in the gas passes:

Top of fuel bed	8.4 lb.
Rear of combustion chamber	17.2 lb.
Base of stack	23.2 lb.

The effects of excess air are graphically shown on the chart on page 165, which is redrawn from *M. Gensch*. An average high-grade and an average low-grade coal were used; commercial coals lie between. The volume of gases goes up rapidly with excess air and may overload the chimney and draft equipment. With admission of excess air the theoretical combustion temperature drops rapidly. The flue temperature relations shown by *Gensch* should be contrasted with results obtained by the *Bureau of Mines* (see page 140). The *Bureau* states that combustion chamber temperature and flue gas temperature rise and fall together, although the plotted results do not show this conclusively.

The *Bureau of Mines* points out that the leakage of air into a boiler setting is significant only when compared with the air entering the furnace through the grate or firing door. The same difference between the gas pressures inside the setting and the outside atmosphere causes the same weight

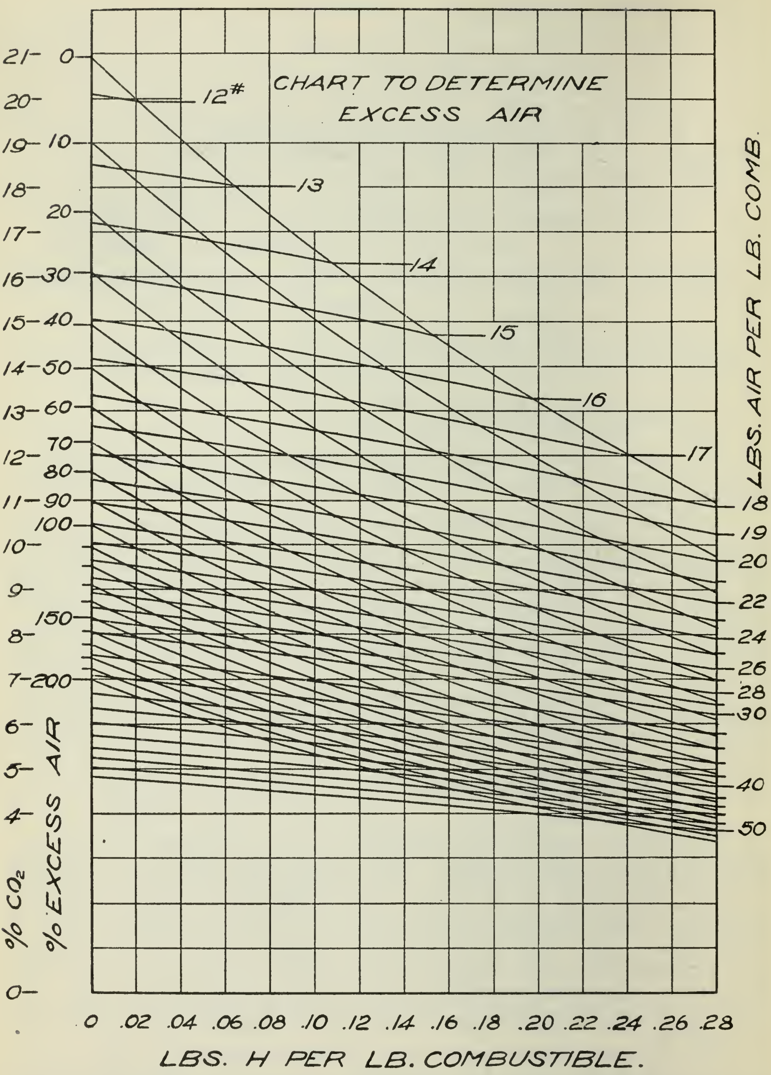
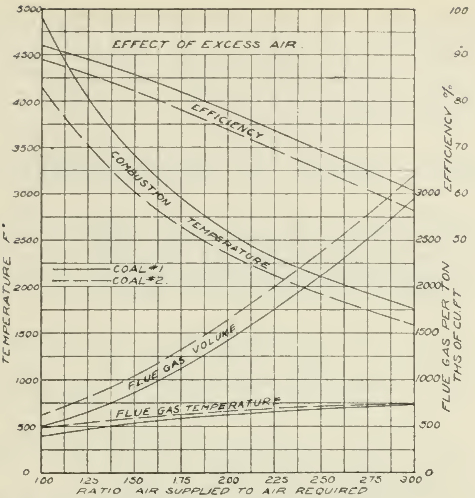


CHART FOR USING % CO_2 IN FLUE GASES TO DETERMINE % EXCESS AIR AND WEIGHT OF AIR SUPPLIED IN BURNING COALS OF DIFFERENT HYDROGEN CONTENT



The two coals are the approximate limits of commercial coals. Volume of flue gases is in thousands cu. ft. per ton at the flue gas temperature and atmospheric pressure and shows how the draft fan would be loaded.

Analysis	Coal No. 1 (as fired)	Coal No. 2 (as fired)
Carbon........	83	51
Hydrogen.....	4	4.5
Sulphur.......	1	2.5
Oxygen.......	4	19
Ash	6	.9
Moisture......	2	14
Heating value (dry coal)	14230 BTU.	10,000 BTU.

DIAGRAM TO SHOW THE EFFECT OF EXCESS AIR ON THE MAXIMUM ATTAINABLE TEMPERATURES AND EFFICIENCIES

of air to leak into a given setting. If the coal burns freely, and no clinker is formed, the air finds little resistance in flowing through the grate and fuel bed, and a large quantity of fuel is consumed. A large quantity of air is also required through the firing door. In such a case the leakage of air through the setting would be a small part of the total air used. In another case the coal may cake badly and the whole fuel bed may become fused. In addition the fuel bed may be very thick. In this case a smaller quantity of air would pass through the fuel bed for the given pressure difference, and the leakage through the setting would be a much larger part of the total air used.

A good way to detect air leakage through holes in the fuel bed is to provide a double differential draft gauge on the boiler front. As the fuel resistance decreases, the draft through the fuel bed drops as compared with the draft through the boiler. The fireman is informed as to the fire conditions without opening the doors. Air leakage through the fuel bed may be more serious than air leakage through the setting. The fires may be too thin on the grates, and the fireman may not be careful to distribute the coal evenly over the grates.

The importance of providing for the admission of the proper amount of air above the fuel bed—secondary air—is shown by the table on page 106. The amount of combustible gases rising from the fuel bed is large. It makes no difference how the air gets in, whether through special openings or through doors and cracks, except that it is essential that it be properly distributed and that the temperature conditions are right for burning the gases.

The loss of heat in the stack gases from excess air can be obtained from the curves under heat balance, page 233.

CARE OF SETTING TO REDUCE EXCESS AIR

The following suggestions by *Hays* are helpful in making a setting tight:

Do not assume that any crack is not conducting air to the heating surface. A crevice between an eye-beam or a stay and the brick work may lead to some hidden avenue that will carry cold air where it will do a lot of damage. Don't forget the brick on top of the boiler. Don't make a casual inspection for cracks.

Use a candle on the boiler setting, also on the boiler headers. Inspect for air leakage at clean-out doors, blow-off pipes, etc.

The loss due to air leaks in a furnace and boiler setting is 10% of the heat generated in the furnace, as a conservative estimate for the average power plant.

Uehling suggests that the air leaks can be located by firing up strongly, opening the damper wide and suddenly closing it tight. Smoke will issue from all considerable cracks.

Air leaks in a return tubular boiler may be caused as follows: Expansion of the boiler may push back the arch, leaving an opening ½ in. wide. The arch may be broken, there may be excessive clearance around the blow-off pipe. There may be loose doors and door frames.

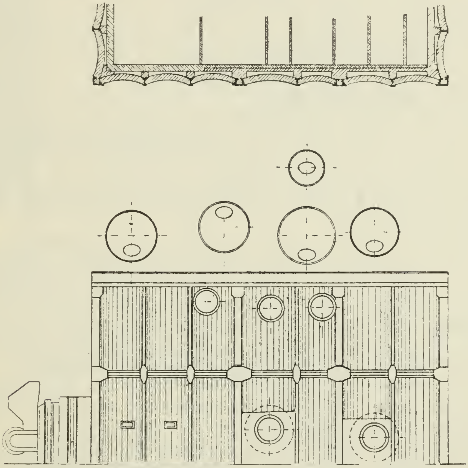
Morgan B. Smith suggests the following repairs for a setting which has very poor joints, in which the bricks are porous and where the door frames are loose. First remove thoroughly the old, worn-out lime mortar in the joints of the brick work to a depth of fully one inch, and clean the bricks with wire brushes. Point up the bricks with mortar of cement and fire-clay. Add enough ammonia to this mortar so that it has a fairly strong odor. This tends to retard the setting and makes the mixture more resistant to temperature changes. Joints should be made flush with the surface of the brick and allowed to set for two days. The whole setting, including the iron work, should be painted with a heavy, slow-drying asphaltum-base paint, giving a flexible coating not easily cracked or peeled off. Three coats of paint should be applied, and the total work on the setting should take about 10 days. This paint is gummy and peels when scratched. There are several such on the market. In one installation before such treatment the % of CO_2 in the gas at the top of the last pass was 8.5%, while after treatment it was 13%, the same as in the first pass.

Hays recommends not to plaster the cracks in a setting. The plaster shrinks and falls out. Caulk them. Make a very thin mixture of fire-clay and cotton waste, first pulling the waste apart so that the fibers of it will be covered with the clay. Use a sharpened piece of wood as a caulking tool. Drive the caulking material in tight. This can be done while the boiler is in operation. There are cements on the market for this purpose.

Old magnesia pipe covering made into paste with water is satisfactory for plugging cracks in the setting. The cracks can also be stopped with asbestos rope or cement. Lime or cement mortar lacks elasticity, and often falls out after drying.

Hays also remarks that the boiler doors are supposed to keep cold air away from the headers, but in most cases do not. "The inflow of cold air around boiler doors is not only bad for efficiency, but is bad for the boiler headers." The headers were probably properly packed. See that the packing is in good shape. The doors may have warped. The catches may not be in proper position, or nobody may have paid attention to their proper closing. This may let in an enormous amount of excess air.

A complete steel casing around the boiler setting, insulated to reduce radiation, prevents air infiltration.



BOW SETTING FOR STIRLING BOILER

The above shows a bow system of walls for setting Stirling boilers, widely used in Germany. The panels of brick wall being bowed toward the inside, the expansion is readily taken up, and a cracked setting is rarely found.

SMOKE

Visible smoke is composed chiefly of very small particles of carbon and tar. When seen under the microscope, the particles are shown to be really clusters of still smaller particles about .00,000,2 inch in diameter. Because of their small size, they are easily carried by even the slowest moving gas-stream. These particles when glowing are the cause of the visibility of the furnace flame. The actual carbon in dense smoke amounts to about 1% of the carbon in the coal. The accompanying loss is due more to combustible gases, which may amount to 3 to 10%.

High CO and smoke in stack gases represent high losses, not so much because of the losses in these two themselves, but because they indicate unburned hydrocarbons. At the same time smokeless combustion does not necessarily indicate perfect combustion.

Hays says that "To burn soft coal smokelessly is a simple matter, but to burn it smokelessly and at the same time economically is different altogether. Nine-tenths of the 'smokeless furnaces' would go off the market if tested with a gas analyzer. A plant that never shows a trace of smoke at the chimney is not burning coal efficiently."

CAUSES OF SMOKE

The following are reasons why furnaces sometimes smoke:

1. The furnaces and the grates are not properly designed to burn the coal available. There is no equipment on the market that will handle equally well all the coals found in the United States.
2. There is a lack of draft.
3. The firemen are unskilled.
4. There is not enough combustion space.
5. Wood, paper and other refuse is burned.
6. The load is changed quickly.
7. Excessive loads are maintained.

Smoke is due to four causes or a combination of them resulting from the above conditions: lack of air, lack of mixture of the air and gases, low temperature and small combustion space.

If the boiler setting is tight, and the gases have no more than 12% CO_2, there is an abundance of air.

If the furnace is white-hot, there is plenty of temperature.

If there is an abundance of air, with CO in the gases, insufficient mixture is the trouble. In practically all cases there is plenty of oxygen in the furnace, but it goes through in streams, and does not mix with the combustible.

Lack of space is probably the most common of all the causes of smoke. The grate must be at such a distance below the heating surface that the flame will be burnt out before the relatively cold metal is reached.

The curve on page 169, adapted from *Paul Fuchs*, represents the density of smoke as a function of the hydrogen content of the coal. The Ringelmann chart is explained in the next section.

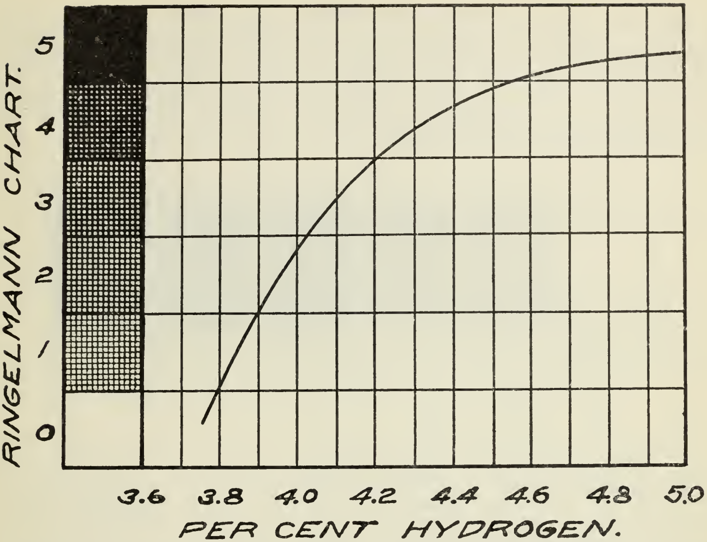
The rate of heating coal, which controls the distillation, directly influences the smoke result. Time, *i. e.*, a large combustion space, is required to burn the tarry vapors.

Contrary to the general opinion, with extremely high temperatures, smoke is produced, and more unburned gases are lost up the stack. High temperature means an approach to the theoretical supply of air, and difficulty of complete mixture is the cause of the smoke.

The table below shows the relations between smoke, CO and temperature obtained at the *St. Louis Testing Plant*. It shows that CO and dense black smoke increase together, that the combustion chamber temperature increases with CO, as suggested above; and that high smoke values and high unaccounted for losses go together.

SMOKE, CO AND TEMPERATURE

	% Black Smoke						
	0	0-10	10-20	20-30	30-40	40-50	50-60
No. of tests	37	18	56	51	36	17	4
Aver. % smoke	0	7.1	15.5	24.7	34.7	43.1	52.9
Aver. % CO in gases	.05	.11	.11	.14	.21	.33	.35
Aver. % unaccounted for in heat bal.	9.14	10.60	9.46	10.93	11.41	13.41	13.34
Aver. combustion cham. temp. Fahr.	2180	2215	2357	2415	2450	2465	2617



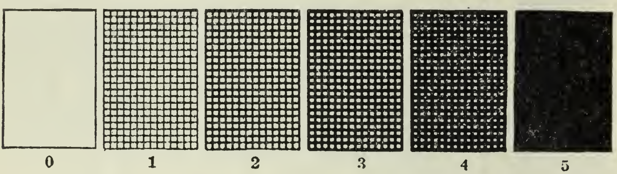
SHOWING HOW SMOKE DENSITY MAY VARY WITH THE HYDROGEN CONTENT OF COAL

SMOKE DETERMINATIONS

No wholly satisfactory method of quantitatively or qualitatively determining smoke has come into use, nor has any reliable method of fixing even the relative density of smoke at different times been evolved. The character of the sky and the background and the personal equation of the observer have a marked effect. A method sometimes employed is to make 1 min. observations and record these according to the degree of blackness. The % values are as follows:

	%
Dense black	100
Medium black	80
Dense gray	60
Medium gray	40
Light gray	20
Very light	5
Trace	1
Clear chimney	0

The most generally used basis of qualitative smoke measurement is the Ringelmann Chart. This consists of four large charts ruled with vertical and horizontal lines forming squares (see page 170). No. 1 is ruled with lines 1 mm thick and spaces 9 mm wide. No. 2 is ruled with 2.3 mm lines and spaces 7.7 mm wide. No. 3 is ruled with lines 3.7 mm and spaces 6.3 mm. No. 4 is ruled with 5.5 mm lines, and spaces 4.5 mm. The cards are placed 50 ft. from the observer, in line with the chimney, together with a white card and one that is solid black. The observer glances rapidly from the chimney to the cards, and judges which one corresponds with the color and density of the smoke. Ringelmann readings are usually taken at ½ to 1 min. intervals during an hour or more. The readings are plotted in a log. This plot gives a good general idea of the manner and regularity of smoke emission, but is very unsatisfactory for comparing stacks.

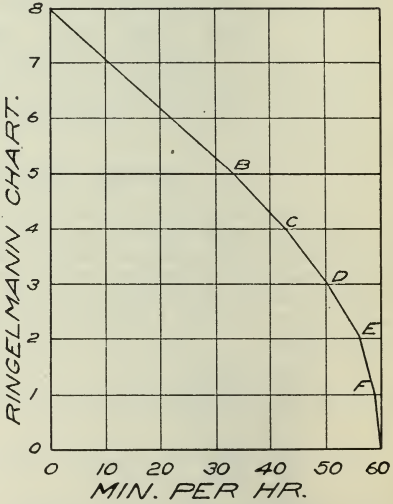


RINGELMANN SCALE FOR GRADING SMOKE DENSITY

Another method of plotting results, suggested by *E. J. Bailey*, is to find the total time during the day represented by each density, reduce it to minutes per hour, and add to it the number of minutes corresponding to each higher density. The totals are plotted against the Ringelmann chart numbers, and the curve represents the fraction of time during which each given degree of smoke density has been reached or exceeded.

Bailey remarks that Ringelmann chart No. 5 includes all smoke that is opaque. Twice as much carbon can be carried at one time as at another, and not affect the density reading.

Admiral R. T. Hall describes an electrical means of determining the density of smoke used on the U. S. S. Conyngham. The basic principle is the sensitivity of the metal selenium to light as affecting the passage of electric current. A selenium disk connected to the ship lighting circuit was placed on one side of the stack opposite a light on the other. The intensity of the beam of light striking the disk of course varied with the density of the smoke. A milliammeter with a suitably graduated scale indicated the changes in current due to the changes in smoke density.



METHOD OF PLOTTING RINGELMANN READINGS

SMOKE PREVENTION

The following measures will assist in the prevention of smoke:

1. The coal should be supplied in small quantities and at frequent intervals. The more nearly the feeding approaches a continuous and uniform supply, the better.
2. The air supply should be slightly in excess of the theoretical requirements. An auxiliary supply at the front or rear of the furnace should burn the gases.
3. The temperature in the furnace should be sufficiently high to ignite the gas.
4. A fire-brick combustion chamber, designed to cause thorough mixing of the gases and air, should be provided, but there should be no fire-brick arch over the grate.

The following table by the *Bureau of Mines* shows the result of tests to determine the best method of hand-firing high-volatile Illinois coals of nut size, using natural draft. The "ribbon" method consisted of firing alternately narrow strips the full length of the grate. This gave the highest efficiency and practically no smoke. The spreading method gave the most smoke and the lowest efficiency.

Method Draft	Efficiency	Black smoke %	Aver. interval between firings, min.	Coal per firing, lbs.	% rated capacity
Ribbon, Natural	62.22	5	2.3	50	106.7
Coking, Natural	60.49	15	7.4	140	95
Alternate, Natural	59.87	15.8	3.5	70	106.5
Spreading, Natural	57.56	32	9.3	170	92.7
Alternate, Forced	60.2	14.9	3.4	85	131.6

Tests on lignite, peat and sub-bituminous coals which have a volatile content of 47 to 67%, showed that they can be burned in hand-fired furnaces with a small amount of smoke.

Briquetting offers hand-fired plants a means of developing high capacity practically without smoke, and at good efficiency. Briquettes gave an efficiency 1 to 3% greater, developed a higher capacity, and were consumed much more completely than the raw coal.

A well-designed and operated furnace will burn many coals without smoke up to a certain rate of combustion, that rate depending upon the coal. Above this rate, the efficiency will decrease, and smoke will result, owing to lack of furnace capacity to supply air and mix the gases.

It is possible to design and operate a boiler plant to burn a high volatile coal with practically no smoke except when a fresh fire is built.

The air admittance to the furnace is very important. Very little free oxygen passes through the fuel bed. Additional air must be admitted through the fire door, through special openings in the fire door or in the dead plate, or through the bridge wall. A combination of all of these may be used. The best method is that which gives the best mixing. Extra air admitted at firing and for a short period thereafter increases efficiency and reduces smoke. Devices for admitting air at the front of the furnace and at the bridge wall appear to be equally effective in reducing the amount of smoke. Where air is admitted only through the fire door or through the dead plate, the mixing is due only to natural diffusion. If additional air is admitted through the bridge wall, the gases are between two streams of oxygen.

Mixing the air and gases by special fire-brick structures, such as deflector arches and wing walls, is satisfactory. The chief objection is the lack of durability. A large combustion space affords more chance for mixing.

Steam jets are sometimes used for assisting in the mixing of the gases and air. They are usually placed above the fire door. The best method is to admit air through small openings around the jet, which acts like an injector. The nozzles should be properly designed to give a high velocity with a small steam consumption. If allowed to run continuously a steam jet probably wastes more of the energy of the coal than it will save. If properly regulated, it will keep a stack clean and save coal. It is an expensive device, all things considered, and its only purpose is to mix the air and gases intimately. It is probable that a part of the dissociated hydrogen from the steam goes up the stack unburned, so that the considerable heat required to break up the steam is lost. Another loss is the heat put into superheating the steam up to the stack temperature.

To assist in smoke prevention, lengthen the travel of the gases from the grates to the heating surface.

As *Jos. Harrington* remarks, the gases are in the furnace only a few seconds. Every foot of flame travel must be made as effective as possible. Any delay in starting the combustion seriously affects the ability to complete it before the gases leave the furnace. A proper place to ignite the gases is the instant they leave the coal. A reflecting ignition arch will do this.

The following deductions are from tests on a return tubular boiler:

1. The operation at rating of a return tubular boiler, hand-fired, is possible without violation of smoke ordinances. However, it requires proper supervision, usually with attention to firing methods not given by the average fireman.

2. Smoke is prevented more easily by the coking method of firing than by the spreading method of firing.

3. The use of supplementary air immediately after firing tends to increase the overall efficiency and to abate smoke.

4. A brick arch directly over the fire and underneath the boiler shell results in lower overall efficiency and in the production of more smoke.

Osborne Monnett has summarized the proper height of furnaces for smokeless combustion in different combinations in the table on page 173.

The effect of mixing arches in a return tubular boiler setting is shown by a series of tests described by *S. H. Viall* on the five settings indicated in the sketches on page 174, which showed the following results:

EFFECTS OF MIXING ARCHES ON FURNACE ECONOMY

Series	A	B	C	D	E	F	G
Type of furnace, Fig. No.	1	2	3	4	5	..	..
Carbon dioxide, per cent	8.90	9.40	9.20	9.10	8.60	11.48	12.70
Carbon monoxide, per cent	0	0	0	0	0	0	0.06
Oxygen, per cent	10.80	10.20	10.50	10.40	11.10	7.49	5.90
Nitrogen, per cent	80.30	80.40	80.30	80.50	80.30	81.03	81.34
Temp. of uptake gases, deg. F.	611	672	665	678	681	430	549
Temperature of steam, deg. F.	333	335	336	343	335	367	369
Diff. between uptake and steam temp., deg. F.	278	337	329	335	346	63	180
Dry stack gases per lb. coal as fired, lb.	15.65	14.98	15.81	15.23	15.55	11.35	12.00
Coal as fired, per sq. ft. grate per hr., lb.	22.63	24.62	24.70	24.80	26.60	22.70	35.70
Draft over fire, in. of water	0.116	0.113	0.226	0.226	0.245	0.090	0.220
Coal per sq. ft. of grate per hr. per 0.01 in. of draft, lb.	1.95	2.18	1.09	1.10	1.08	2.52	1.62
Moisture in coal as fired, per cent	15.40	16.30	10.10	11.30	10.90	15.90	15.20
Combustible in coal as fired, per cent	73.50	73.32	76.77	73.89	75.02	70.75	70.72
Ash in coal as fired, per cent	11.10	10.38	13.13	14.81	14.08	13.35	14.08
B. t. u. per lb. coal as fired	10,674	10,716	11,225	10,618	10,728	9,872	10,032
Combined boiler and furnace eff., per cent	50.20	57.50	53.90	55.10	56.50	72.67	72.55
Heat losses accounted for	28.80	29.11	28.40	30.49	32.30	16.27	23.08
Heat losses unaccounted for	21.00	13.39	17.70	14.41	11.20	11.06	4.37

Headroom Requirements for Smokeless Settings

Copyright by Osborne Monnett

(All dimensions in inches)

FURNACES:	Horizontal Return Tubular Boilers 54	60	66	72	Water Tube Boilers Hor. Baff. 1-1½" Pitch	Vert. Baff. 1-1½" Pitch	Hor. Baff. 3¼" Pitch	Vert. Baff. 3¼" Pitch	Continental or Scotch Marine
	(Shell to dead plate)				(Front header to floor)				
Hand-Fired:									
No. 6	32	34	34	36	72	*	78	*	**
No. 7	36	40	40	42	†	†	†	†	**
No. 8	32	34	34	36	72	*	78	*	**
	(Shell to floor)								
Down draft	60	60	60	60	72	*	78	*	*
McMillan	52	54	60	60	72	*	78	*	**
Twin fire	58	60	62	64	72	*	78	*	*
Semi-ext. refuse burning	††	††	††	††	84	*	90	*	*
Gravity Feed:									
Burke	48	48	50	54	60	*	66	*	Full extension
McMillan	48	48	50	54	60	*	66	*	Full extension
Chain grate	72	72	78	78	84	114	96	120	**
Front Feed:									
Moore	48	54	60	60	72	102	78	108	**
Roney	60	60	60	72	84	108	90	120	**
20th Cent.	54	60	66	72	84	108	90	120	**
Side Feed‡									
Detroit	66	72	78	84	90	*	96	*	Full extension
Model	66	72	78	84	90	*	96	*	Full extension
McKenzie	66	70	70	70	90	*	96	*	Full extension
Murphy	66	72	78	84	90	*	96	*	Full extension
Under Feed:	(Shell to dead plate)								
American	42	42	42	42	78	96	84	102	**
Jones	36	38	40	42	78	96	84	102	Min. diam. of furnace 36 in.
Taylor	**	**	**	**	84	102	90	108	**
Westinghouse	**	**	**	**	84	102	90	108	**

---

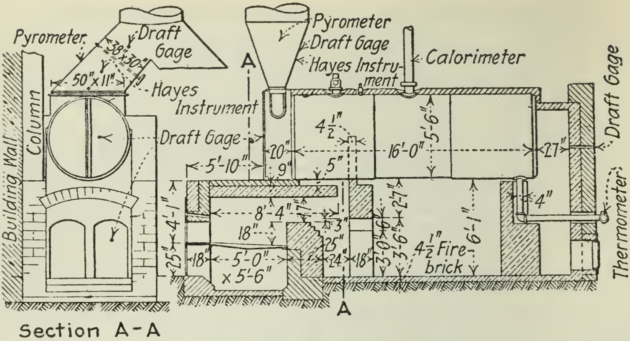
* Combinations not recommended as smokeless settings.

** Combinations not ordinarily met with in practice.

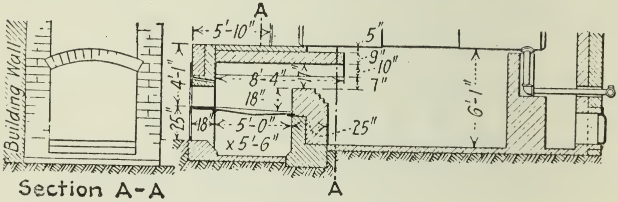
† Not adapted to water-tube boilers.

††Applied only to water-tube boilers. No. 8 better for H.R.T. boilers.

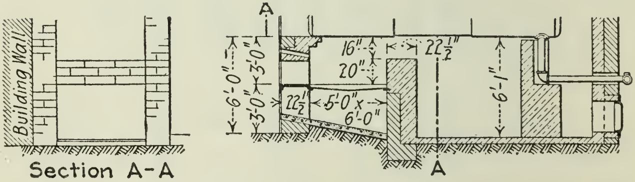
‡ Exceptionally wide settings will require more head room to take care of extra spring of arch.



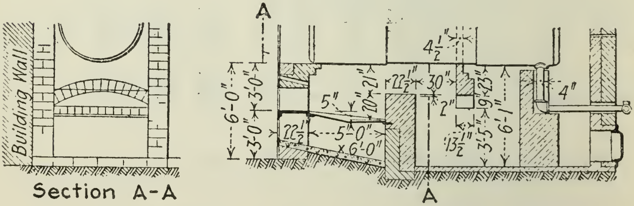
1. FULL EXTENSION, TWO-SPAN DEFLECTION ARCH SETTING



2. SAME AS 1, BUT WITH DEFLECTION ARCH REMOVED

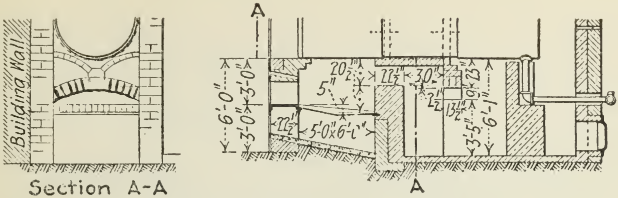


3. PLAIN OR COMMON SETTING



4. PLAIN SETTING WITH DEFLECTION ARCH

SETTINGS TESTED FOR EFFECT OF MIXING ARCHES



5. DOUBLE-ARCH BRIDGE-WALL FURNACE

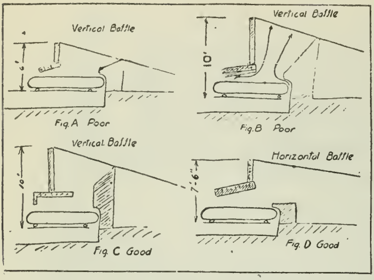
The tests were all made upon the same boiler, under conditions which made them comparable. The gas samples were taken at a point above the damper. The brick setting, which was five years old and cracked, permitted considerable air infiltration. Undoubtedly the CO_2 was between 2 and 4% higher in the combustion chamber at the end of the flame. The CO_2 figures are therefore only a relative indication of the conditions at the end of the flame.

In the A test, a deflection arch was used, while in the B test an open furnace was used. The unaccounted losses are 21% and 13.39% respectively. In the latter case, the gases made only one right-angle turn between the fire and the rear end of the combustion chamber, as compared to three turns when the deflection arch was used. These results do not check apparently with the statement that turning the gases betters the mixture and reduces the unaccounted for losses. It may be explained, however, that during the A test a thin fire was carried and holes were frequently burned through. Radiation from the brick roof and the side of the furnace caused a distillation of almost explosive violence when fresh coal was supplied. There were therefore alternate periods of excess air followed by shortage of air during distillation. The CO_2 readings indicate that the excess air was not serious. The high unaccounted for losses may be due to bad sampling of gases, bad analysis, especially for CO, or incorrect flue-gas temperature determination. During the B test, the fires were carried a little thicker, and the fire-doors were left open a few inches for a few seconds to a minute or so after each firing. This admitted the air when most needed. The decrease in unaccounted for losses indicates that much of the volatile combustible had been oxidized.

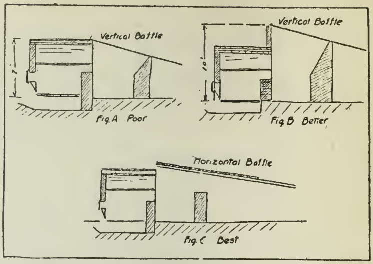
In the C series, the unaccounted losses were 17.7%. In the D series, the gases made two additional right-angle turns in passing from the fire to the rear of the boiler. This produced a better mixture, and the unaccounted for losses decreased. The accounted for losses in the stack and ash-pit were greater, but the decrease in the unaccounted for losses resulted in a net gain in efficiency of 1.2%.

Spreading fresh coal on the fire cooled the furnace. The temperature above the fire may drop below the ignition point of some of the distillates, which may retard, although not stop, distillation. Particles of liquid oil will continue to be driven off from the coal. The heat in the furnace may not be sufficient to evaporate all of the oil, and raise the resulting gas to an igniting temperature. The setting in Fig. 5 was developed to overcome these difficulties. The function of the brick-work in the double arch and the deflection arch is to cause the gases to dip and turn as steam does in passing through a separator. The oils are precipitated on the brick-work and held until gasified. The hot brick-work then ignites the gases.

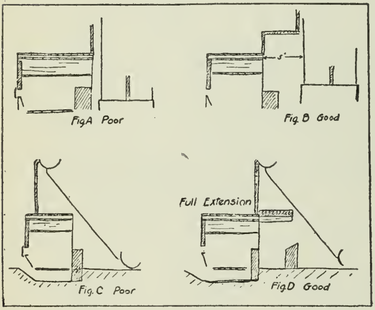
Exposing the fire on the grate to the cooling influences of the boiler shell, as in Settings 3, 4 and 5, lowers the average furnace temperature below that obtained in a fire-brick enclosed furnace. The distillation is less rapid and



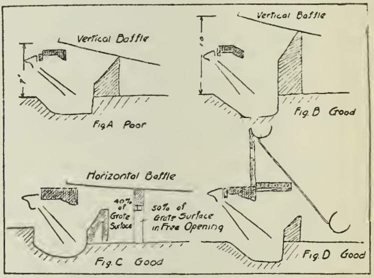
1. SOME CHARACTERISTICS OF CHAIN GRATE SETTING



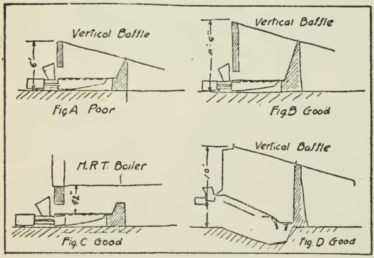
2. DOUBLE INCLINED STOKERS AND HORIZONTAL WATER-TUBE BOILERS



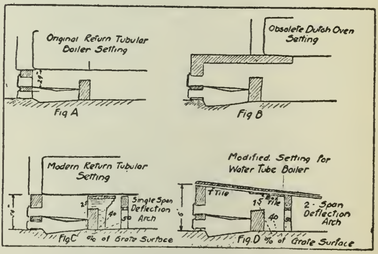
3. DOUBLE INCLINED STOKERS AND VERTICAL BOILERS



4. COMBINATION OF FRONT FEED STOKERS



5. HEAD ROOM FOR UNDERFEED STOKERS


Original Return Tubular Boiler Setting
29"
Fig A
Obsolete Dutch Oven Setting
Fig B
Modern Return Tubular Setting
Single Span Deflection Arch
25
40
50
Fig C % of Grate Surface
Modified Setting for Water Tube Boiler
Tile
Box Tile
15
40
50
6'
2-Span Deflection Arch
Fig. D % of Grate Surface

6. DEVELOPMENT OF HAND-FIRED FURNACE

PROPER AND IMPROPER DESIGNS OF FURNACES FROM STANDPOINT OF SMOKE PREVENTION

more uniform, allowing more time for air to enter the furnace for burning the combustible gases.

The unaccounted for losses in the E series were 3.2% less than in the D, and 6.5% less than in the C series. The efficiency was better. This shows that double arches and deflection arches are a benefit, and do to some degree effect the purpose for which they are provided.

It may be thought that such variation in losses can occur only in a badly operated hand-fired plant, but to show that such losses will occur in the best plants, tests F and G have been added. These data are from two tests upon a 300 H.P. vertically-baffled horizontal water-tube boiler, equipped with a chain-grate stoker burning Illinois screenings. The construction of the plant, and the general plan and skill of operation were unusually high class.

Osborne Monnett presents the sketches on page 176 as proper and improper designs of furnaces.

Fig. A on plate 1 is typical of the older practice in chain-grate settings, with low, short, flat arch, poor ignition and low capacity. The deadening effect of the bank of tubes is to extinguish the flame before combustion becomes complete, in the same manner that a wire netting will kill the flame from a gas burner, the result being a great deal of smoke. It must not be inferred, however, that mere length of flame-travel is always sufficient to insure a satisfactory setting. It has been found that on a long gas pass, unless some positive means are taken to cause a mixture, the gases frequently become stratified and do not mix, in which case the combustion cannot be complete.

In Fig. B the boiler has been raised to 10 ft. under the header, and the ignition arch lengthened to 5 ft., with full extension. This allows more flame-travel, but the setting still has some of the defects of the first one. The rich volatile matter may pass into the bank of tubes in an uninterrupted current in the front part of the furnace, while most of the oxygen necessary to burn the volatile matter is passing in at the back part. There is lack of mixture, and consequently incomplete combustion and low economy.

In Fig C the above defects are corrected by using a longer arch, setting the stoker farther under the boiler, decreasing the floor space occupied, and narrowing the furnace throat opening, so that the volatile gases and air mix in a high temperature zone, which usually completes combustion on a 10 ft. setting. Openings from 18 to 36 in. have been tried with success, the smaller ones being high in maintenance. A 30-in. throat opening is about the most satisfactory.

Another factor which has had a marked effect on the performance of the later chain-grate settings has been the height of the ignition arch at the grate. Where 11 inches was formerly the standard height for a flat arch, it has now been increased to 15 inches, and the slope of the arch has been increased to 2 or 3 inches per foot. Where the arch is sprung against the furnace, it now sets 9 inches above the grate at the skewback, with a 9-inch spring, making 18 inches at the center of the arch.

Fig. D, Plate 1, shows a setting which may be considered ideal for a chain grate. 6 ft. 6 in. may be considered the minimum headroom allowable.

Plate 2 shows a setting with a double-inclined type of stoker. The short length of flame discharging directly into the bank of tube is undesirable when the fire is being worked. This type of stoker is often found installed in a seven-foot headroom, as in Fig. A.

One of the safest arrangements is to provide a tile roof setting with an auxiliary bridge-wall, as in Fig. C. This breaks up the current of gases, and insures mixture. The importance of setting this type of furnace with maximum flame-travel is not always realized.

Plate 3 shows vertical and Sterling boilers with double-inclined furnaces. It is a safe rule to get a full extension on this type of furnace and never resort to the flush-front setting.

Plate 4 shows settings with a front-feed stoker. The same points should be observed as regards flame-travel as with double inclined stokers, to get good results with vertically-baffled water-tube boilers. With a horizontal baffle it is a simple matter to use this type of stoker successfully. Sufficient headroom only is required to get the stoker under the front header. Sometimes piers or deflection arches are used. Where the free opening in such a setting does not go below 40% of the grate surface of the stoker, such construction is desirable.

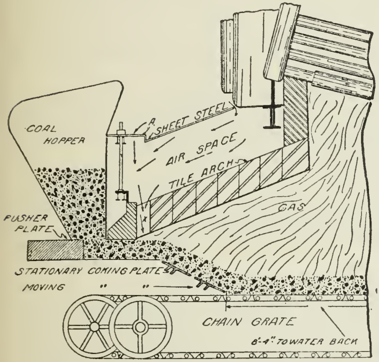
Plate 5 shows a different type of underfeed stoker, requiring different headroom. The Jones and American types give excellent results with a headroom of 8 ft. 6 in. for a vertically-baffled boiler, and 7 ft. for a horizontally-baffled boiler. In the case of horizontal return tubular boilers, these types of stokers can be installed with 42 in. from grate to shell.

With stokers of the Taylor type, Fig. D, a 10-ft. clearance is ideal.

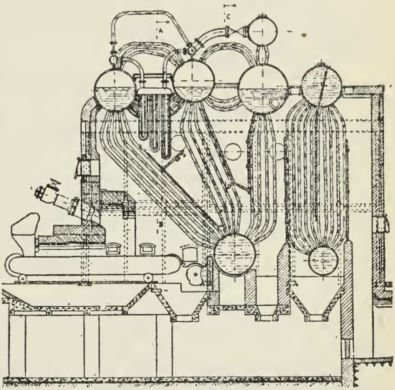
Plate 6 shows settings for hand-fired furnaces. Fig. A is a setting which is fairly efficient commercially, but is very smoky with high volatile coals. The Dutch oven setting in Fig. B was an attempt to improve the plain hand-fired setting. From a smoke standpoint, this Dutch oven setting is a poor combination. The high radiation from the brick-work above the fire has the effect of distilling the gases so rapidly that puffs of dense smoke will be made after every firing, in spite of all effort to prevent them. Fig. C shows how to correct this defect, by baring the shell to the direct radiation of the fire. This increases the steaming capacity, and provides a high temperature zone back of the bridge-wall, where the gases must mix positively against the deflection arch, and so promote combustion.

It is not practicable to combine a hand-fired coal-burning furnace with a vertically-baffled water-tube boiler, but it is a simple matter to arrange such a furnace with a horizontal baffle, carrying out the same idea as in Fig. C. The ordinary hand-fired, horizontally-baffled water-tube boiler furnace is covered with block tile, and has nearly all the defects of the Dutch oven shown in Fig. 3. Fig. C indicates how this can be overcome, by putting T-tile on the second row of tubes over the fire, thereby avoiding the radiating effect of a mass of fire-brick, and by installing a two-span deflection arch to break up the current of gases. There should be from 20 to 25% of the grate surface in free opening above the bridge-wall. The free opening from the back of the bridge-wall to the deflection arch should not be less than 40% of the grate area, while the free opening under the deflection arch should be 30% of the grate area. Hand-fired furnaces for high pressure work should be fitted with four air-syphon steam jets placed across the furnace above the fire-door.

The accompanying illustration by *C. B. Hudson*, shows an arrangement which is reported to have been successful in preventing smoke from a Green Chain Grate installation. Originally a mixture of bituminous slack from the Knoxdale plant of the Pittsburgh & Shawmut Coal Co. and anthracite screenings from the Northern Anthracite Co., Bernice, Pa., was burned, using about 1.2 lb. screenings to 1 lb. slack. The slack coked easily, and the particles of anthracite adhered to the coke, presenting a thick impervious fuel bed. By stopping up all air leaks around the front of the furnace, a high CO_2 was produced. Due to the exigencies of war-times, it was necessary however to change over to all bituminous and difficulty was at once found in getting a good CO_2 without making objectionable smoke. To remedy this, six 1½ in. holes were drilled through the ignition arch at the point X, where the gate tile and the arch come together, and the sheet steel cover plate A was removed. This cut down the objectionable smoke by about 75%, and tests for CO_2 taken just over the tubes in the first pass showed CO_2 at times as high as 17.5%, with but little black smoke. Upon another boiler, the number of holes was increased to 13, with still better results and CO_2 readings, and CO_2 as high as 17 to 18% is at times obtained, readings of 15 to 17% being common. The introduction of secondary air at the point shown gives an excellent mixture and immediate combustion of the volatile distilled from the fresh coal. The breeching damper is controlled according to the indications of a duplex differential draft gauge, showing the draft drop through the fuel bed and the draft drop through the boiler.



SMOKE PREVENTION WITH CHAIN GRATE



SPECIAL STIRLING BOILER

The cut to the right shows a four-drum Stirling boiler with a superheater and economizer, designed by *B. N. Broido*, with a chain-grate setting designed to burn coal or coke-oven gas, or both at peak loads. The boiler contains 3800 sq. ft., the superheater 650, and the economizer 1900. *Broido* states that a fire-brick arch over the furnace is an important feature in the setting of Stirling boilers, and that its design depends upon the kind of fuel used, and the capacity of the boilers. In general, however, the grates should not be set flush, but should extend sufficiently to the front of the boiler to give a good igniting action. For a 4-drum boiler which will not be heavily overloaded, and for average good coal, an ignition arch about 5 ft. long gave good results. The distance between the grate and the arch at the front was for the above conditions usually made 12 in., and a distance of about 20 in. was allowed at the end toward the boiler tubes, to provide more space for combustion. For carrying heavy overloads he advises that the grate should not be too short. On high loads the short grate was smoked badly on account of the thick coal bed, and a portion of the fuel would reach the end of the grate and fall into the ash-pit unburned. With the setting shown, tests upon coal of about 13,000 BTU. per pound gave furnace temperatures of 1880° with 8% CO_2, 2280° with 10% CO_2, 2675° with 12% CO_2, and 2860° with 14% CO_2. Due to the intense radiation from the large grate surface and the fire-brick arches, the first section of the boiler generated 60 to 80% of the entire quantity of steam.

BURNING OIL FUEL

Marks states the requirements for burning oil as follows:

1. Its atomization must be thorough.

2. When atomized, the requisite amount of air, but the minimum amount for complete combustion, must be brought into contact with it.

3. The mixture must be burned in the presence of a refractory material, which radiates heat to assist in ignition. The fire-brick must be high grade, to withstand the temperature.

4. To avoid smoke, the combustion must be complete before the gases are cooled by the boiler heating surface.

5. There must be no localization of heat on the heating surfaces, such as might be produced by blow-pipe action of the burners, or overheating and blistering will result.

Burners.—The term burner is really a misnomer, for its function is to atomize the fuel to effect complete combustion.

Oil burners are of two types, spray and mechanical. Steam spray burners are almost universally used, except for marine work or other cases where the loss of steam and the consequent requirement of additional make-up water is a consideration. Air spray burners have practically gone out of use.

Nelson gives as the essentials of a steam atomizer burner: simplicity, cheap renewal of wearing parts, economy in steam and production of a flame of a shape that makes good combustion, and hence high burner efficiency. The flat flame is preferable, because it uses less steam, and the shape of the flame permits the proper mixture of air.

Steam spray burners are of the inside or outside mixing type. In the former, steam and oil come into contact inside and the mixture is atomized in passing through the burning nozzle. In the latter type, steam passes through a narrow slot or row of small holes below a similar slot through which the oil flows. The oil is picked up by the steam outside the burner and atomized.

The general type of flat flame burners is a tip with two small parallel and horizontal slots. The oil flows out of the upper in fan shape onto the fan-shaped jet of steam from the lower.

Mechanical atomizing burners are of the round flame type. Oil is fed under pressure, varying with the rate at which it is to burn. A rotary motion is given to the oil in passing through the nozzle. Heating the oil aids in the atomization.

Marks says that with the spray burner about 2% of the total steam generated by the boiler is required for atomization. With the mechanical burner, about ¼ of 1% is required for heating and pumping.

Nelson says that the location of the burners depends on the type of boiler. For a boiler with a long unobstructed furnace, such as a horizontal return tubular, a Heine or an Erie City, the burner fits in the firing door satisfactorily. For short-furnace boilers, the best arrangement is to put the burner at the back, shooting toward the front of the boiler. In either case, air should be admitted to the furnace through a checkerwork of fire-brick on the grate bars. The shape of this should approximate the shape of the flame, to reduce excess air. The area of the openings should be equal to 4 sq. in. per boiler H.P. The burners should be supplied with dry steam. Take the connection from the top of the auxiliary steam header. Steam connections should be made for blowing out the oil and steam piping and the ducts in the burner when it is shut down. Strainers in duplicate should be provided in the oil lines.

Air Supply.—The principal consideration affecting efficiency is the proper control of air supply. The waste gases should be analyzed periodically, and a record kept of the flue temperature. No difficulty should be experienced in getting 13 to 14% CO_2. Allowing for excess, about 250 cu. ft. of air under standard conditions should be used per pound of oil. With proper combustion, the flame is dazzling white for about 6 in. from the burner; then becomes gradually transparent; runs into violet, and toward the end changes to red With too little air, no violet is seen, the red darkens, and smoke appears.

Storage.—Noxious and explosive gases heavier than air evolve from fuel oil, necessitating ventilation of the storage container, and isolation from ignition sources.

Fuel oil is viscous. *Nelson* found that Mexican oils of 12 to 18 degs. Baumé should be heated to 110 to 130° F. to make them flow from the storage tank. A thermometer should be provided at the pump.

Pumps.—*Nelson* recommends a duplex steam pump, piston type, with brass valves, metallic packing in the oil piston, and special gaskets and piston-rod packing. The pump size should be based on a very low piston speed. It should have an air chamber on the discharge side, to steady the pressure; a governor on the steam end, to maintain the pressure constant, and an enclosed relief valve. The delivery pressure varies from 40 lb. for oil of 26 to 30 degs. Baumé to 80 lb. for oil of 12 degs. Baumé. Duplicate pumps should be installed and equipped with strainers. The suction lift should be a minimum. The pipes should be as straight as possible, with bends in preference to elbows.

Heating.—Practically all fuel oils require heating to facilitate atomization. The heater should have ample heating surface, which should all be utilized. A steam coil in a vessel of oil tends to local heating. A good type of heater passes the oil at high velocity through a long brass coil heated by steam on the outside. The temperature to which oil must be heated for feeding to the burners varies with viscosity. *Nelson* says that for the usual fuel oils in the South, 180° to 220° F. is satisfactory, the higher temperature being for an oil of 12 degs. Baumé. 8 or 9 degs. Engler would be the proper viscosity. After the oil has been properly heated at the pump, care should be taken to keep it at this temperature until it reaches the burners. If the line is very long, an exhaust steam pipe can be run through the center of it. A by-pass should be provided from the burner end of the supply pipe back to the pump, so that after a shut-down the pipe may be filled with hot oil. With much of the heavy oil in use, it is impossible to light the burner until hot oil reaches it.

Furnace.—It is essential to have ample combustion chamber space. A Dutch oven would give very good results. The use of a target wall is not necessary, and may cause overheating of the surface.

Efficiency.—The *U. S. Naval Liquid Fuel Board* tested 17 different burners, obtaining an equivalent evaporation varying from 11.48 to 13.96 lb. steam per lb. of oil. In stationary plants the equivalent evaporation ranged from 14 to 16 lb. *Lucke* says that an average efficiency of 4 to 6% above that for coal firing is obtainable with oil fuels. The Liquid Fuel Board obtained an efficiency 5% greater than coal for the same rate of evaporation and could increase the boiler capacity by 50%, still maintaining the same efficiency as with coal. The maximum efficiency with oil was obtained at a higher rate of evaporation than was the maximum efficiency with coal.

BURNING GASEOUS FUELS

Marks' Handbook says that natural gas is best burned by the use of a number of small burners, each capable of handling approximately 30 rated boiler H.P. This obviates the danger of blow-pipe action, which might be present with large burners. The burners should be evenly distributed over the lower portion of the boiler front. The combustion space should be about 2 cu. ft. per rated H.P. A checkerwork wall is not necessary.

For burning blast furnace gas under boilers, a long flame-travel and ample furnace volume should be provided, about 1½ to 2 cu. ft. per rated HP. The burners should permit of regulation of both air and gas. The question of handling dust when burning this fuel is important, as it is difficult to remove when allowed to accumulate and fuse.

With gas passages of .8 sq. in. per rated H.P., a boiler will produce rated capacity with a gas pressure of 2 in. water column. The pressure in the main is usually from 6 to 8 in., which allows for overload and throttling.

POWDERED COAL AND ITS COMBUSTION UNDER BOILERS

The use of pulverized coal under stationary boilers is limited, although for twenty years it has been used with great success in the cement industry, and more recently in metallurgical processes. The experience gained in these fields, in drying, pulverizing, storing and conveying powdered coal applies directly to its use under steam boilers. The main problem seems to be in the design and maintenance of the furnace.

Extensive experiments by railways on the use of powdered coal for locomotive firing are summed up in a report presented at the May, 1916, meeting of the *Railway Fuel Association*, which mentions the following advantages:

1. Smokeless, sparkless and cinderless operation.
2. Maintenance of maximum boiler pressure within an average variation of 3 lb. without popping of the safety valve.
3. An increase of from 7½ to 16% in boiler efficiency, as compared with burning lump coal on grates.
4. Saving from 15 to 35% of fuel.

The committee was of the opinion "that the effectiveness and utility of the use of fuel in pulverized form has been demonstrated from the past year's development, and that the progress in this method of stoking and burning bituminous coal, anthracite and lignite for generating power and light on railways will be quite marked from now on."

Views with reference to the use of powdered coal in stationary plants are given below:

From the viewpoint of the theorist, the use of powdered coal forms one of the best methods ever proposed for the promotion of combustion and commercial economies. As compared with the gas producer or the mechanical stoker, the powdered coal burner is the only instance in which the solid fuel is gasified and completely consumed directly within the chamber desired to be heated. In actual practice but a small fraction of 1% is lost in the flue gas or slag pan. Efficient combustion is obtained. Each particle of coal is surrounded by air, and on account of the fineness, practically instantaneous oxidation occurs. It is now possible to control the temperature without sacrificing any material gain due to it. The air supply can be definitely controlled.

Plant Required.—The use of powdered fuel necessitates a plant which will furnish a very fine product, for the coal must burn while suspended in the air. The large particles will fall to the bottom of the furnace, and they must be removed with the slag and ash.

High Temperature.—Very high temperatures are obtained and there is direct contact of the flame and brick-work. The blow-pipe effect of the high velocity jet may act to melt out or erode the brick-work, and the fused ash at the bottom of the combustion chamber may present difficulties in removal. Difficulty was also experienced in early experiments because of the deposit of liquid slag on the heating surfaces. If the temperature is kept down by feeding less fuel, the capacity is limited, or if it is kept down by using an excess of air, economic advantage is sacrificed.

Joseph Harrington and *W. A. Evans* believe that powdered coal will not revolutionize stationary plants immediately. *Harrington* says that with powdered coal, the loss in the ash-pit and flue does not exceed 1%, while with the best mechanical stokers the ash loss will not exceed 2% of the coal fired. A probable advantage of 2 or 3% in combustion efficiency in favor of powdered fuel is offset by the cost of fuel preparation. It is not reasonable to anticipate that better than 96% furnace efficiency can be obtained, and this figure can be obtained by a mechanical stoker.

Grades of Coal for Pulverizing.—*Harrington* says that the greater the volatile combustible content, the more readily will the powdered coal ignite and burn, and the less dependent will be the process upon the size and proportions of the combustion chamber. As the volatile content decreases, more dependence must be placed upon the proportions and location of the surrounding brick-work in order to maintain the temperature for ignition. Even anthracite has been burned in a pulverized form. It must be very finely ground and burned in a rather confined space, so that the ignition will be prompt and aided by nearby brick-work.

A. L. Agnew gives as the average analysis for coals for pulverizing:

Volatile matter	39%
Fixed carbon	53%
Ash	8%
Sulphur	2%
BTU per lb	13600

Drying.—Moisture has detrimental effects, (1) reducing the capacity of the grinder, (2) giving a tendency to pack in the storage bins, (3) lowering the possible obtainable temperature, and (4) decreasing the efficiency. The concensus of opinion is that coal should be practically dry; 1% of moisture being the maximum amount with which pulverizing can be properly effected. ½% moisture is the figure which is ordinarily required. Under these conditions the pulverized coal remains quite fluid. The coal is crushed previous to drying. Rotary cylinders with external furnaces are generally employed, the gases from the furnace in some cases passing through the cylinder.

Pulverizing.—In order that the fuel may remain suspended in the carrying air, the proper standard of fineness is: 85% through a 200 mesh screen and 95% through a 100 mesh screen.

Pulverizing machinery is divided broadly into air separation machines and screening machines. In the former, an upward current of air from a fan has sufficient carrying power to take with it the finest particles but will not lift the coarser. These particles are collected in a cyclone separator, which is vented in a way to prevent loss of dust. In screening machines, the coal is continually thrown against a screen, which permits the fine particles to pass through, while the coarser ones fall back under the rolls. Pulverization can also be effected in a tube mill or ball mill with an expenditure of power and cost not greatly different from that of the other types.

The cost of pulverizing per ton depends entirely on the daily quantity of coal pulverized. The accompanying table by *Joseph Harrington* is representative.

COST OF COAL-PULVERIZING PLANTS AND COST OF PULVERIZATION

This table is based on the following data:

Labor rates per hour: Millers, $0.20; drier firemen, $0.175; common labor, $0.15.

Cost of drier fuel, $0.03 per net ton. (Based on coal with 7% moisture at $2.60 per ton, delivered, and 6 lb. evaporation per lb. of coal burned.)

Repairs, $0.05 per net ton. (This includes whole pulverizing plant, covering all machinery.)

Power, $0.102 per net ton pulverized. (Based on consumption of 17 hp-hr. per ton pulverized and cost per HP. per annum of $45.00.)

Interest and Depreciation based on 10% of cost of plant and 300 days' operation per year.

Daily Capacity, Net Tons	Total Cost of Pulverizing, Cents per ton		Cost of Plants Including Buildings, Dollars	Number of Men Required	Number and Size of Fuller Mills Required	Labor Cost Cents per Net Ton
	Interest and Depreciation not Included	Including Interest and Depreciation				
5	70.0	....	4,000*	1	1—24-in.	45.00
10	48.2	96.3	14,500	1	1—33-in.	30.00
20	37.4	61.9	14,500	2	1—33-in.	20.00
30	35.8	51.8	14,500	2	1—33-in.	17.40
40	33.6	47.0	14,500	2	1—33-in.	15.30
50	32.0	44.1	18,150	3	1—42-in.	13.80
60	31.0	41.4	18,150	3	1—42-in.	12.75
70	30.2	37.8	18.150	4	1—42-in.	11.85
80	29.3	36.7	18,150	4	1—42-in.	11.10
90	28.4	36.4	18,150	5	1—42-in.	10.25
100	27.7	36.2	25,620	5	3—33-in.	9.50
110	27.0	34.7	25.620	6	3—33-in.†	8.80
120	26.4	33.5	25,620	6	3—33-in.†	8.30
130	25.8	32.9	25.620	7	3—33-in †	7.69
140	25.4	31.5	26,150	7	2—42-in.	7.14
150	25.0	30.6	26,150	7	2—42-in.	6.80
160	24.7	30.0	26,150	7	2—42-in.	6.50
170	24.5	29.6	26,150	8	2—42-in.	6.20
180	24.3	29.1	26,150	8	2—42-in.	6.00
190	24.0	28.5	40,130	8	3—42-in.	5.92
200	23.9	31.0	40,130	9	3—42-in.	5.75
210	23.8	30.5	40,130	9	3—42-in.	5.47
220	23.7	30.4	40.130	9	3—42-in.	5.22
230	23.6	30.2	40,130	9	3—42-in.	5.00
240	23.5	30.1	40,130	10	3—42-in.	5.00
250	23.4	30.0	40,130	10	3—42-in.	5.00

---

* Cost of building not included.

†Two 42-in. mills have the same daily capacity.

Storage.—Care in the storage of pulverized coal is essential. In itself it does not contain the elements required for combustion. The dust will take fire very easily, often a lighted match being enough to ignite it, but in mass it simply smoulders away harmlessly. Damp pulverized coal should never be stored for any length of time, as spontaneous combustion is likely to occur. 96 hr. is a safe limit for dry coal. The hopper should have two sides sloping at about 30° with the vertical. This prevents the coal from arching. It should be free from pockets where the powdered coal will lodge and remain stored for some time. Its capacity should be sufficient for only 12 to 14 hours' use and it should be covered to prevent the accidental introduction of fire or foreign matter or the absorption of moisture, which is rapid. Coal has been stored, however, for a period of a week or 10 days in pulverized form. Powdered coal should always be kept moving, and not allowed to stand more than one day in case of a temporary shut-down.

Conveying and Feeding.—The conveying of powdered fuel is usually accomplished by screw conveyors. Pneumatic conveyors are also used. Where the path of travel is vertical, a bucket conveyor in closely-fitting chambers is employed. *H. C. Barnhurst* says that in furnaces and in conveying pipes there should be a slight vacuum at all times so that leakage will be toward and not from the furnace. The stack draft should be sufficient to create this slight vacuum in the furnace and prevent the back travel of combustion into the pipe.

At the Parsons plant of the M. K. & T. R. R. 3 oz. station pressure feeds the fuel to the burner nozzle, where higher pressure air takes it up. *J. V. Culliney* says that the high pressure should range between 4 and 6 oz.; the low pressure or volume air blast between 1 and 2 oz. An air blast of 6 oz. picks up more coal than it can furnish with oxygen, so that additional air must be provided, at usually ½ oz. pressure, according to *W. A. Evans*.

The manufacturers of certain powdered fuel equipment claim that preliminary crushing, drying, storage and conveying of powdered coal is unnecessary. One such device on the market receives the coal as delivered, pulverizes it and blows it directly into the furnace with an amount of air claimed to give perfect combustion.

Burners.—There are broadly 3 types of apparatus for feeding and burning powdered coal under boilers. In the first the coal is emptied into a hopper above a feed-controlling mechanism and carried into the furnace by natural draft. The *Pinther* is typical. In the second type the feed is mechanical, as in the revolving brush of the *Schwartzkopff* apparatus. In the third type the coal is blown into the furnace.

Harrington says that there is a great diversity of opinion as to proper type of burner. It is generally conceded that the best results are obtained when the coal is carried into the furnace in a stream of air, the volume of which is just sufficient to supply the oxygen for complete combustion. The velocity of the entering jet must be greater than the rate of flame propagation, to prevent burning back into the pipe. The mixing of coal with air must be in fairly close proximity to the furnace, for two reasons: 1st, the mixture is explosive, and should be of no greater extent than necessary, and 2d, there is a tendency for the coal to separate, thus destroying the uniformity of mixture. The production of this uniformity is both important and difficult, and if the mixing is at some distance from the furnace, means must be provided for agitating the air current so that the fuel cloud may remain of constant density.

Evans says that the control by air of the feed to the burners, rather than by the screw conveyor of variable speed, seems to work out to better advantage, for the reason that any speed control is bound to be bungling and not of sufficiently fine adjustment. A good burner should operate within 3% variation in quantity of coal, for any number of 5 min. intervals, for any given setting of its controller.

Furnace.—According to *Evans*, the essentials for a furnace for burning powdered coal are means for maintaining a temperature of at least 2000° F. throughout, and a large combustion space, at least 1 cu. ft. for each 3 lb. of coal burned per hr. A 600 HP. boiler subject to a peak load of 1800 HP. should have the burner 15 ft. vertically below the tubes. Return tubular boilers usually have a large combustion space, but offer difficulty from low temperature. He has never been able to maintain combustion under them except by an auxiliary igniting flame.

Barnhurst describes the combustion chamber at the Parsons plant of the M. K. & T. R. R., which has a volume of 583 cu. ft., or a normal rating of 36.4 cu. ft. per lb. of coal fired per min. The bridge wall is 7 ft. from the front of the setting. The boilers are horizontally baffled, the lower baffle completely surrounding the lower row of tubes, to protect them from the direct action of the flame, and to present to the entering fuel a surface composed entirely of refractory fire-brick at high temperature. The bottom of the combustion chamber consists of a hopper with three sloping sides, the front being vertical, so that the ash discharge can be drawn directly through a door in the ash tunnel into steel cars. The bottoms of the ash doors are located 7 ft. below the floor of the boiler room. The area between the top of the bridge wall and the bottom row of brick-protected tubes is 19 sq. ft. With a temperature in the furnace of 2800° F., the velocity of the gases at normal rating will be about 16 ft. per second. With such a low velocity, the greater part of the combustion is completed before the gases reach the bridge wall, and the ash is deposited in the hopper bottom. There is also a settling chamber back of the bridge wall. After being put in operation, it was found that the horizontal baffles permitted an accumulation of too much ash. A Dutch oven approximating a 6 ft. cube was built in front of the boiler, and vertical baffles were replaced by horizontal ones. This was due to the fact that the Kansas coal contained a high ash content, about 22%.

Ash Difficulties.—*Evans* says that whenever ash has a chance to deposit in the range of the flame, slag will form of a sticky, sluggish nature, almost impossible to remove. It chills solid at 1800° F., or as soon as a door is opened to break it out.

Section III—Heat Absorption

HEAT TRANSMISSION

Three modes of propagation are concerned in the transfer of heat from the fire to the water in the boiler, as follows:

Some heat is radiated directly from the incandescent fuel bed to the boiler tubes or plates. This heat does not appear as sensible heat of the gases. The quantity of heat so transmitted would not be lessened, but might be slightly increased, if there were a vacuum between the fuel bed and the metal.

Heat is transferred to the heating surfaces by convection in particles of gas. Cooled particles of gas next to the heat-absorbing surface are continually being replaced by hotter particles, due to movement of the gases.

Heat passes by conduction from the particles of hot gas in contact with the soot coating into the soot and then through the metal and the scale into the particles of water next to the scale.

The diagram on page 188, due to the *Bureau of Mines*, shows the temperature relations as heat enters, travels through and leaves the boiler plates.

The dry surface of the heating plate may be defined as the thin layer of gas near or at the outside surface of the soot coating, where the heat ceases to travel by convection and starts to travel by conduction.

The wet surface of the heating plate is similarly defined as the thin layer of steam or water near or at the surface of the layer of scale away from the metal plate, where the heat ceases to travel by conduction and starts to travel by convection, facilitated by the circulation in the boiler.

HEAT TRANSMISSION BY CONDUCTION

The quantity of heat transmitted through a unit area of plate in a unit of time is related to the conductivity and to the difference in temperatures between the dry and wet surfaces of the plate as follows:

$$H = \frac{C}{D}(t_1 - t) \text{ wherein}$$

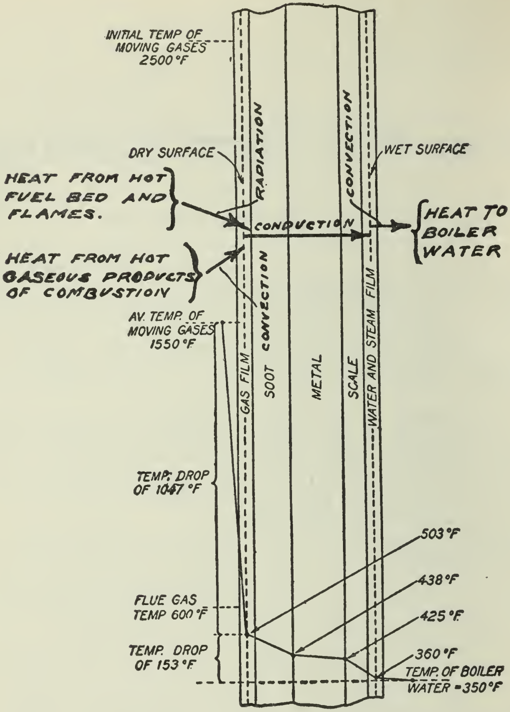
H = quantity of heat transmitted per sq. ft. of the heating plate in BTU. per hr.

C = coefficient of conductivity of 1 in. thickness of the substance between the dry and wet surfaces, in BTU. per degree F. temperature difference per sq. ft.

D = distance between the two surfaces in in.

t_1 = temperature of the dry surface, in degs. F.

t = temperature of the wet surface, in degs. F.



DIAGRAMMATIC ILLUSTRATION OF THE WAYS IN WHICH HEAT ENTERS, TRAVELS THROUGH AND LEAVES A BOILER PLATE

THE TEMPERATURES SHOWN ARE THOSE INVOLVED IN CONVECTION AND CONDUCTION

The coefficient of conductivity C for the above units is 2904 times the C. G. S. unit given in scientific tables. Different materials have conductivities represented by the following coefficients:

Aluminum	1394 at 64° F.	Water	4.16 at 68° F.
Copper	2666 at 64° F.	Fire brick	4.5
Cast iron	314 at 64° F.	Air	.165 at 60° F.
Wrought iron	418 at 64° F.	Hydrogen	1.6 at 60° F.
Soft steel	322	Conductivity of a perfect vacuum would be zero.	
Hard steel	180		

The conductivity of all substances varies with the temperatures in a manner not fully appreciated. Although a theory has been proposed which would indicate that the thermal conductivity of solids is constant, it appears that most solids decrease in conductivity with increase in temperature. There is hardly enough data for liquids to say whether the coefficient increases or decreases. In gases, according to the kinetic theory, the coefficient of conductivity is proportional to the specific heat at constant volume times the coefficient of viscosity. This seems to hold well for permanent gases. If it does, the temperature factor in the coefficient of conductivity for air is, according to *Bell,*

$$\frac{C_vT^{3/2}}{T + 185}$$

where C_v is the specific heat at constant volume and T is the absolute temperature in F. degs. The change with pressure in a gas is probably negligible, as the coefficient of viscosity is independent of pressure.

Clerk Maxwell offers the following for the coefficient of conductivity for gases:

$K = m\ C_v \times$ constant

m is the coefficient of gas viscosity and C_v is specific heat at constant volume.

m is proportional to the 3/4 power of the absolute temperature T, therefore

$K = cC_vT^{3/4}$.

The coefficient of conductivity of air at 60 degs. F. is .165 BTU per sq. ft. per hour per degree. At 1000 degs. F. the factors by the two expressions for gas conductivity give results as follows: Bell .331 BTU, Maxwell .356 BTU.

Heat flow encounters a resistance through joints in metal bars, or between plates at the point of contact. With this in mind, boiler seams in contact with fires are forbidden.

The conductivity of iron at 400° F., according to the *Smithsonian Physical Tables*, is equivalent to C = 259. This means that if the two surfaces of a steel plate 1 in. thick are kept at a temperature difference of 1° F., every sq. ft. of the surface will transmit 259 BTU. per hr.

At the usual rating of 10 sq. ft. of heating surface per Boiler HP., the heat transmitted per sq. ft. per hr. is

$$\frac{34.5 \times 970.4}{10} = 3350 \text{ BTU.}$$

The average boiler tube is 1/10 in. thick, and therefore can pass heat 10 times as easily as the same material 1 in. thick, or 2590 BTU per hr. To pass the heat through the walls of the tube at the above rate would require only

$$\frac{3350}{2590} = 1.29° \text{ F. difference of temperature.}$$

This shows that the resistance of the metal can be but a very small part of the total resistance. The soot and scale coatings generally present add to the resistance to heat transfer. Suppose that in a well-kept boiler the resistance to heat transfer of the soot and scale is 10 times that of the metal alone. This would give a total drop of 14.2° F. between the dry and wet surfaces of the tube. Even this is a small difference, and indicates the possibility of working the surface at high rates.

In one test the difference of temperature between the two surfaces of the tube ⅛ in. thick in a Heine boiler was 41.5° F. This means that

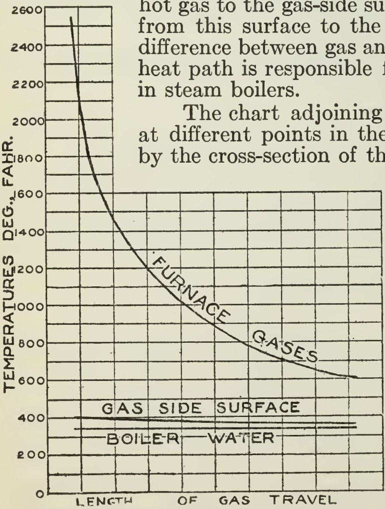
$\frac{259 \times 41.5}{1/8}$ = 86,000 BTU per hr. per sq. ft. of area were transmitted through the tubes. This is approximately equal to 2.57 boiler HP. per sq. ft. of heating surface, or 1 boiler HP. per .39 sq. ft. of heating plate. It should be noted that the temperature of the boiler tube is close to the temperature of the boiler water, and is affected very little by the hot gases.

HEAT TRANSMISSION BY CONVECTION

The cut on page 188 shows relatively the average temperature drop between the hot moving gases and the boiler water when the initial temperature of the gases is 2500° F., and the boiler is working at 10 times the usual rate of working a boiler. The drops from the dry surface to the metal, and from the metal to the wet surface, are assumed, although it is probable that the drop on the dry side to the metal is much higher. These values are estimated, but observation indicates that they are close to the facts.

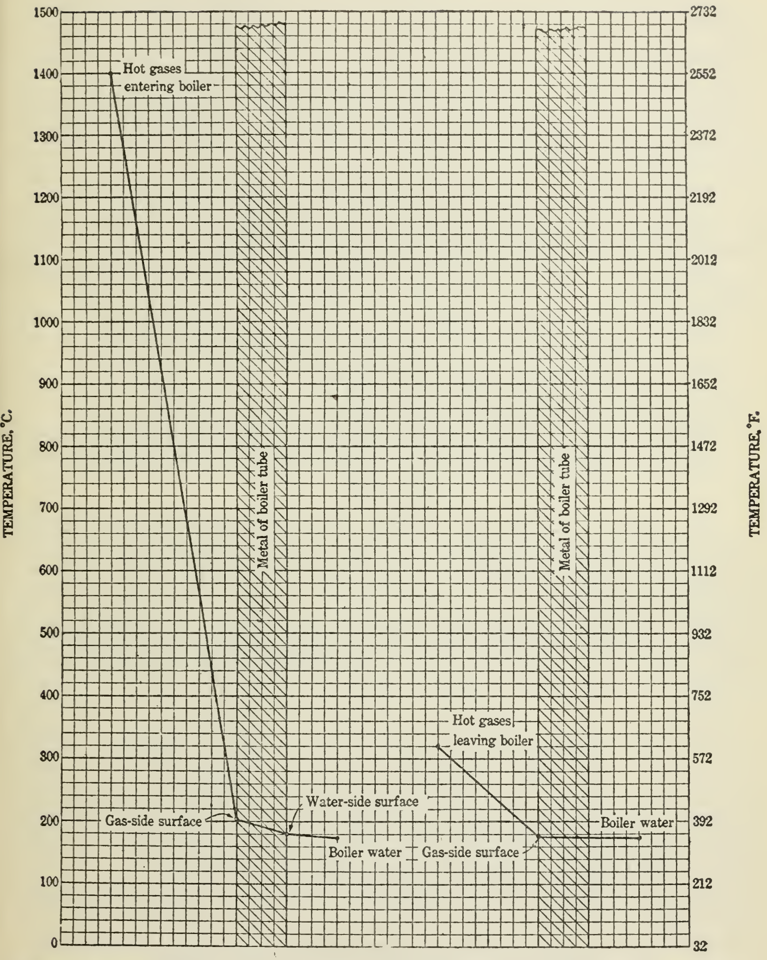
The principal resistance to heat transmission in a boiler lies between the hot gases and the dry surface. On the inside of the boiler, the water on account of its great heat capacity, in which is included the relatively great heat of vaporization, readily takes the heat from the surface of the tubes, provided there is sufficient circulation, so that the temperature drop at that point is usually small. It is the process of getting the heat through to the dry surface, by radiation and convection, that is slow.

The *Bureau of Mines* made a series of determinations of the temperatures of the furnace gases, the flue gases, the water in the tube and the temperature of the inner and outer surfaces of the tubes of a Heine boiler. The chart on page 191 shows the temperature drop along the path of heat travel from the hot gases into the boiler water. The startling feature, particularly in the diagram to the left, is the large temperature drop from the hot gas to the gas-side surface of the tubes, and the small drop from this surface to the boiler water. The large temperature difference between gas and metal indicates that this part of the heat path is responsible for the low rate of heat transmission in steam boilers.



PROBABLE TEMPERATURE DROP

The chart adjoining shows the temperature of the gases at different points in the gas passage. This curve is affected by the cross-section of the gas-passages of a water tube boiler, and by the size of the tubes in a fire-tube boiler. The shape of the curve representing the temperature of the gas-side surface is no doubt similar to the curve representing gas temperatures. The temperature of the water is very nearly constant, and therefore is represented by a straight horizontal line. *Kreisinger* says that this curve is from actual measurements, corrected for radiation errors. Measurements made with different sizes of thermocouples were used to obtain the temperatures for zero diameter thermocouple, which would be correct. See page 140.



TEMPERATURE DROP ALONG THE PATH OF HEAT TRAVEL FROM THE HOT GASES INTO THE BOILER WATER

Diagram on left, temperature drop at place where hot gases enter boiler; temperatures same as given on line **AB**, figure on page 193. Diagram on right, temperature drop at place where gases leave boiler. In this diagram the horizontal distances have no significance.

In modern boilers by far the greatest part of the heat is imparted to the heating surface by convection. The heat evolved by the combustion of the fuel appears principally as sensible heat of the gases. Regarding convection, *Osborne Reynolds* states: "The heat carried by air or any other fluid from a surface, apart from the effect of radiation, is proportional to the internal diffusion of the fluid at or near the surface; that is, is proportional to the rate at which particles or molecules pass backward or forward from the surface to any given depth within the fluid." This rate of distribution has been shown to depend on:

1. Natural internal diffusion of the fluid when at rest.

2. Eddies caused by motion in mass, which mixes the fluid up and continually brings fresh particles into contact with the surface.

J. E. Bell writes the formula originally due to Osborne Reynolds as follows:

$$H = (a + bw)(T - t)$$

wherein H = heat units transferred per unit of tube surface per unit of time,
T = mean temperature of the fluid,
t = temperature of the tube wall,
a = constant, probably proportional to conductivity,
b = constant that is proportional to the specific heat, and also varies with the temperature in some way that so far seems obscure,
w = mass flow per unit area of the channel.

The quantity a expresses the effect of the natural diffusion of the gas. The quantity b expresses the effect of motion. It includes density and velocity.

If the velocity is high, bw becomes large in comparison with a, which then may be neglected.

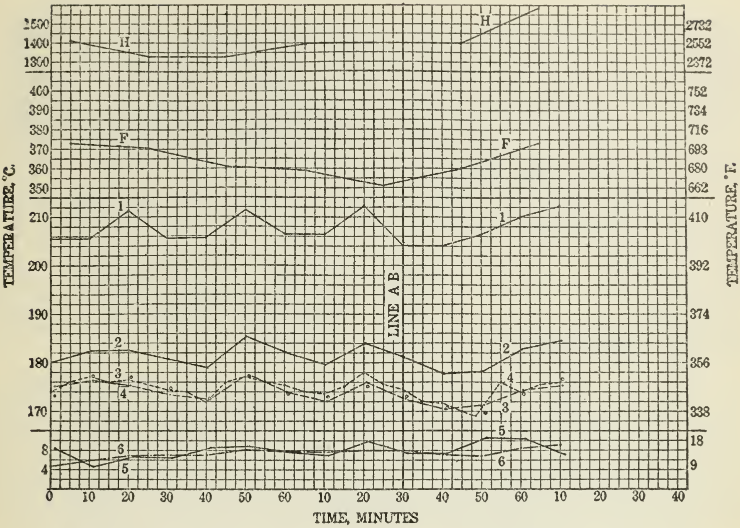
The quantity to be multiplied by the temperature difference $(a + bw)$ is usually called the transfer rate, and is distinguished by R. For gases, it varies from 2 to 12 BTU. per sq. ft. of surface per hr., per degree F. of temperature difference, and for water from 400 to 3000 BTU., depending on the mass flow.

Kreisinger shows curves of the variation of velocity of air in an 8-in. pipe, and the variation of temperature across the pipe. There is a marked resemblance. The largest temperature drop is within a short distance of the surface of the pipe. He believes there is little doubt that the drop in velocity is the cause of the drop in temperature, that is, as the velocity decreases near the wall of the pipe, the transfer of heat by convection is reduced, and the heat has to be transferred by conduction, which in gases is a slow process, and therefore a high temperature gradient is required.

See section on "Heat Transfer from a Fluid in a Channel to the Wall," page 197.

HEAT TRANSMISSION BY RADIATION

Stefan stated empirically, and *Boltzmann* later deduced from the theory of electro-magnetic radiation, that the loss of energy from a body emitting full radiation, that is, a so-called black body, is proportional to the bounding surface and to the fourth power of the absolute temperature. Expressed in BTU. per hr. per sq. ft. of surface, the radiation from such a body at a tem-



TEMPERATURE READINGS IN CONDUCTIVITY TEST

H, temperature of gases entering boiler; **F**, temperature of gases leaving boiler; **No. 1**, temperature of the gas-side surface of a boiler tube in the lowest row at a place where the hot gases enter the boiler; **No. 2**, temperature of the water-side surface of the same tube; **No. 3**, temperature of the steam according to pressure; **No. 4**, temperature of boiler water obtained with copper-tube thermocouple; **No. 5**, difference between the temperatures of the water-side surface and those of the boiler water; **No. 6**, difference obtained by subtracting the values of curve **4** from those of curve **2**. Average rate of equivalent evaporation, 4.4 lbs. per sq. ft. of gas-side surface per hr.

perature of T degrees F. absolute is very nearly

$$1600\left(\frac{T}{1000}\right)^4$$

Very hot bodies, regardless of their physical characteristics, seem to emit heat at nearly the above rate. At lower temperatures, the physical surface characteristics have an influence, but incandescent carbon is almost a perfect "black body." In most cases, in addition to hot surfaces, cooler surfaces are present to absorb radiant heat. These surfaces in turn radiate at rates dependent on their temperatures. The net effect is measured by the difference between the amount emitted by the hot body, and that returned by the cooler. The net transfer of heat in BTU. per hr. per sq. ft. between two parallel planes is

$$H = 1600\left[\left(\frac{T}{1000}\right)^4 - \left(\frac{t}{1000}\right)^4\right]$$

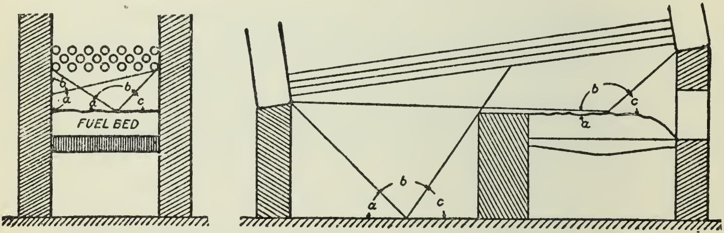
T = temperature of hotter body in absolute degs. F.,
t = temperature of colder body in absolute degs. F.

In very few cases is the exchange between surfaces as simple as between two parallel "black body" planes. Boiler tubes receive heat by radiation from the very hot fuel bed, from the brick wall, and from the flame. *Bell* says, "Under these circumstances it is not possible to make any accurate calculation as to how much heat can be exchanged by radiation, even though it is assumed that Stefan's law applies. Nevertheless, if it is conceived that the radiation is from a black surface at the temperature a pyrometer would show in the flame, the radiant heat absorbed is, I believe, not far different from that given by Stefan's law."

As stated above, the constant 1600 in Stefan's law applies to black bodies. The following values for different substances are derived from *Marks' Handbook:*

Black body	1618	Wrought iron, highly polished	467
Lamp black	1540	Cast iron, rough, oxidized	1570
Brass, dull	362	Lime plaster, rough white	1510
Copper, slightly polished	278	Water	1120
Wrought iron, dull, oxidized	1540		

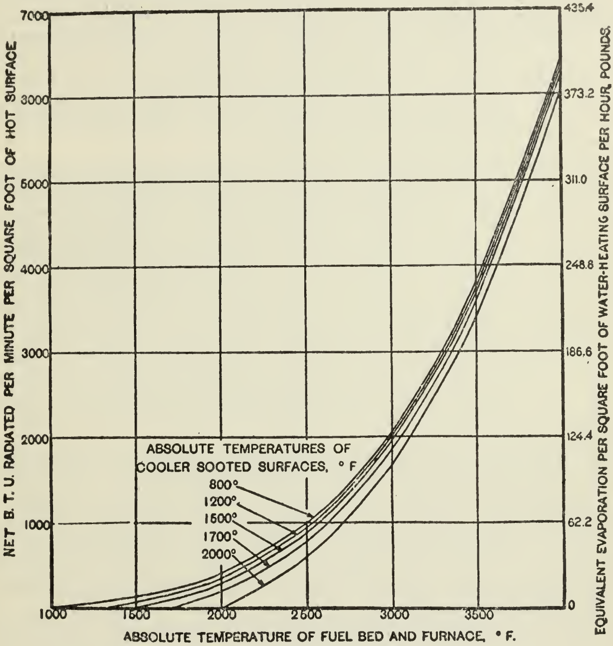
The locomotive furnace presents a simple practical problem in radiation. The hot surface is the fuel bed, and the cold surface is the combined surface of the tube sheet, the crown sheet, the front sheet and the plates on both sides of the fuel bed. The only other exposed part of the furnace is the fire door, which subtends a very small angle of the fuel bed vision, and can be neglected. The heat received by the boiler by radiation then depends upon the area of the fuel bed, and not upon the form of the boiler heating surface.



APPLICATION OF STEFAN AND BOLTZMANN'S RADIATION LAW TO AN EXTERNALLY FIRED BOILER

In furnaces of externally-fired boilers, any problem of heat radiation is a more complicated one. On the assumption that the temperature of the furnace lining is the same as that of the fuel bed, the fuel bed and the furnace walls may be designated as the hot surface, therefore any portion of the hot surface will be exposed not only to the cold surface of the boiler, but also to other parts of the hot surface itself. Referring to the above sketch, it can be seen that any portion of the hot surface is exposed to the boiler at a solid angle b, and to other parts of the hot surface itself through the angles a and c. The coefficient in the equation should be multiplied by the solid angle b of exposure, expressed as a fraction of a spherical angle of 180°, to obtain the net heat radiated by each portion of the hot surface to the boiler. In any given case of this type, it would not be difficult to get the approximate average angle of exposure of the fuel bed and the walls by averaging the angles of exposure of four or five small distributed portions of the hot surface.

From the equation, it is apparent that the quantity of heat a boiler receives by radiation increases very rapidly as the temperature of the furnace rises. Increasing the furnace temperature from 2000° to 3000° F. will nearly quadruple the amount of heat imparted to the boiler by radiation. A drop in temperature from 2500° to 2400° F. will reduce the amount of heat transferred by radiation by 12%. The effect increases much more rapidly with higher temperatures.



RELATION BETWEEN FURNACE TEMPERATURE AND QUANTITY OF HEAT IMPARTED TO A BOILER BY RADIATION FOR SEVERAL CONSTANT TEMPERATURES OF THE SOOT COATING ON THE WATER-HEATING PLATES

The above chart shows the relation between furnace temperature and the quantity of heat imparted to the boiler by radiation, for constant temperatures of the soot coating on the tubes.

Bell experimented to find how much heat is absorbed by a boiler by radiation. A long tube in a B. & W. boiler was replaced by a shorter one of the same size, extending through the front header and just entering the first baffle. Water was circulated through it, its quantity and temperature were measured. The heat absorbed corresponded to an evaporation of 75 lb. per sq. ft. of surface per hr.; more than 10 times the average for the boiler. The top surface did not receive radiation, and the bottom surface, besides radiation, also received heat due to the impingement of the furnace gases.

If two-thirds of the surface is considered effective, the evaporation would correspond to 112 lb. per sq. ft. per hr. Bell believes that more than 100 lb. was from radiation, and 12 lb. from the heat of the first impingement of the gases. As the gases were at about 2500° F., the evaporation checked with Stefan's law as accurately as could be expected.

The rate of net heat radiation is per sq. ft. of the totally exposed hot surface, and not per sq. ft. of the boiler heating surface. At the same temperatures, the net quantity of heat exchanged between the hot surface and the boiler surface depends on the extent of the hot surface and the angle of exposure of the hot surface to the boiler surface. Neither the distance nor the shape of the boiler surface makes any difference.

In addition to the heat radiation from the fuel bed and the furnace walls, the luminous flame radiates considerable heat. As flames vary in size and shape with different fuels, the rate of combustion and the supply of air, it is difficult to calculate their effects.

It has been sufficiently proven that the temperature of the gases leaving a boiler varies almost directly with the temperature of the gases entering the boiler, both temperatures being reckoned above that of the boiling water. If two boilers have exactly similar construction and baffling, the gases in the one that was so set that it received more heat by radiation from the furnace will have the lower initial and final gas temperatures, and the efficiency of the boiler will be higher. The gases radiate but little heat to the boiler, but part of the heat generated by the combustion of the fuel is radiated by the hot fuel bed, the flames and the furnace to the boiler, and is never absorbed by the gases, therefore the latter enter the boiler at a lower temperature than they would if they absorbed all the heat generated in the furnace. This means that any heat which the boiler gets directly by radiation is a clear gain. Of course, the presumption is that combustion and air supply is the same in both cases.

The *University of Illinois* ran two series of tests on Heine boilers, the one with the baffle covering the lower row of tubes and the other with the lower row of tubes exposed. The second series gave a considerably lower flue gas temperature, and an overall efficiency 3 to 5% higher, with but very little smoke. The absorption of heat from the fuel bed and the flames, if carried to an extreme, might result in incomplete combustion and smoke.

Summarizing, it can be said that the quantity of heat imparted to a boiler by radiation depends

(*a*) On the extent of the hot surfaces of the furnace and the angle of exposure to the cold surfaces of the boiler.

(*b*) On the difference of the fourth powers of the absolute temperatures of the hot and cold surfaces.

In any given steam generating apparatus, the first of the above conditions is fixed, and cannot be used to increase the output of the boiler. It should be noted, however, that where the fire bed is under the boiler much more heat is transmitted by radiation than where the fire is enclosed in a Dutch oven. As to the second, it may be said that in well-operated plants the furnace temperatures cannot be raised much higher without approaching the fusing temperature of the ash and causing deterioration of the furnace lining. It is, therefore, advantageous first to transmit a considerable part of the heat directly by radiation, as this permits of a higher CO_2, without unduly raising the furnace temperature.

For the effect of radiation on the measurement of temperatures in boiler practice, see page 140.

HEAT TRANSFER FROM A FLUID IN A CHANNEL TO THE WALL

Bell gives a formula for the transfer of heat between a fluid in a channel and the wall, obtained by equating the heat absorbed by the tube walls, using the transfer equation for convection, to the heat lost by the fluid. The discussion assumes that the fluid is hotter than the walls, but if the walls are the hotter, the same equations apply, with slight changes. The formula assumes a transfer rate or coefficient which is multiplied by the difference between the mean gas temperature and the mean tube temperature to find the total transfer, and which covers all the methods of heat transmission:

$$H = SR\left(\frac{T_1 + T_2}{2} - \frac{t_1 + t_2}{2}\right) = W\,c\,(T_1 - T_2)$$

wherein T_1 = temperature of the gas at the hot end of the conduit,
T_2 = temperature of the gas at the cold end,
t_1 = temperature of the wall at the hot end,
t_2 = temperature of the wall at the cold end,
S = surface in sq. ft.,
W = weight of flow of gases in lb. per hr.,
c = specific heat,
H = heat transfer in BTU. per hr.,
R = coefficient of heat transmission in BTU. per hr. per sq. ft. per deg. F. temperature difference.

The more exact differential equation is

$$dH = (T - t)\,RdS = -\,WcdT.$$

To determine the transfer rate, R, *Bell* conducted a series of experiments at Bayonne for the B. & W. Co., from which he deduced the following:

$$R = 2.1 + .000626\,[1 + .000575\,(T - t) - .000000866\,(T - t)^2]\,w$$

wherein w is the weight of gas in lbs. per sq. ft. of tube sectional area per hr. and T and t are mean gas and wall temperatures respectively. The experiments covered the full range of gas temperatures met with in the boiler, but did not show the variation with tube temperatures. Mr. Bell believes that this value can be used without serious error for different tube temperatures and for different tube diameters. The expression is entirely empirical.

When the gas flow is at right angles to the tubes, as in a horizontal, cross-baffled boiler, the mean transfer rate is very nearly

$$R = 2 + .0014w$$

wherein w is the total weight of gas in lb. per hr. divided by the net area in sq. ft. between the tubes in one row, averaged between the different passes.

The value of b = .0014 is greater than the value of the constant in the expression applicable to a circular flue, which is probably due to the staggering of the tubes. It must be remembered that for the same velocities the friction loss would be more. For the same friction loss the value may be not much different. *Carrier* has suggested that, approximately, in two structures in which the pressure drop of the gases is the same the same rate of heat transmission is obtained.

At very high velocities, the coefficient of heat transfer is almost directly proportional to the gas flow, and a given area of surface would cool a hot gas the same number of degrees regardless of the amount of gas swept over it. At lower velocities, the first term in the expression for the transfer rate is relatively of more importance. In boiler work, around rating, the gas flow is about 1000 lb. per sq. ft. of net gas passage area per hr. The transfer rate is 3.4, of which about 2 is from the constant term a and 1.4 from the term bw = .0014w, which varies with the gas flow. It is therefore to be expected that flue gas temperatures should increase as the capacity increases, and this is true, although it is partly to be explained by the fact that the amount of heat received by the boiler directly from the fuel bed by radiation is a smaller percentage of the whole at higher capacity, resulting in a higher initial temperature of the gases.

Regarding the assumption, originally due to *Rankine*, that heat transfer is proportional to the square of the temperature difference, *Kreisinger* says, "Since the rate of heat radiation is proportional to the difference of the fourth powers of the absolute temperatures, and the rate of convection contains the temperature factor as a first power, in the combined rate of heat transfer the temperature factor may appear as the third power or as the square, depending upon whether the radiation or convection predominates. The formula where the square of the temperature difference appears can be applicable only in very special cases."

The integration of the differential equation $(T - t)\ RdS = -WcdT$ for the case where one of the temperatures is constant, as in a boiler, gives the following expression for calculating the surface required for a given cooling effect:

$$S = \frac{Wc}{R} \log_e \left(\frac{T_1 - t}{T_2 - t} \right)$$

S = surface in sq. ft.,
W = pounds of gases per hr.,
c = specific heat of gases,
T_1 = temperature of gases at hot end,
T_2 = temperature of gases at cold end,
t = temperature of boiler tube.

Bell says that this equation, together with the expression for the heat transfer rate, and the equation for heat transmission by radiation from the furnace are all the heat transfer formulæ necessary for the design of boilers as regards heat absorption. There is no such thing as a theoretically best length of tube or of gas channel. The greater the heating surface and the longer the gas travel the lower the flue gas temperature and the higher the efficiency. Against this must be balanced the increased fixed costs and the greater draft requirements. Instead of increasing the amount of boiler surface unduly, an economizer or air heater or both can be used, thus gaining the advantage of a greater difference in temperature between the gases and the heated fluid.

If, in place of the transfer rate R, its reciprocal is used, an expression is obtained which measures the resistance to heat passage, which is entirely analogous to electrical resistance. The total resistance in a boiler or economizer is the sum of three separate and distinct terms, that from the gas to the tube surface, that through the tube itself, and that from the tube to the water. The tube resistance, and the resistance from the tube to the water, are negligible compared with the resistance on the gas side. For example, in condensers the conductivity from steam to water may, under conditions of high water velocity and air free steam, exceed 1000 BTU. per hr. per sq. ft. per deg. F. temperature difference. This is so much greater than the transmission rates secured in boilers and economizers that it warrants the use of formulæ for the latter without reference to the velocity of circulation of the water. *Bell* evolved the following formula for transfer rate from a tube to water contained in it from Stanton's experiments, lowering the first term:

$$R = 50 + 467 \left(1 - \frac{.133}{d}\right) v$$

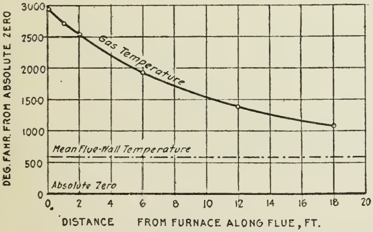
v = the velocity of the water in ft. per sec., and is used in place of w, the weight, because it is simpler, and the density does not vary.
d = diameter of the tube in in.

Lawford H. Fry gives the following empirical formula for determining the drop in temperature of a gas flowing through a flue:

$$\log\log_{10} \frac{T_1}{T} - \log\log_{10} \frac{T_2}{T} = MD$$

wherein $\log_{10} M = 1.558 - .185d - (.14 + .083d) \log_{10} W$
T_1 and T_2 = mean abs. temperatures of gas at two points in the flue.
T = means abs. temperature of metallic wall.
D = distance between points, in ft.
d = 4 times hydraulic depth, in in.
= diameter in case of circular flues.
W = gas flow in lb. per hr.

This formula was derived by consideration of data obtained by the *Babcock & Wilcox Co.*, as plotted in the adjoining figure, relating to the flow of furnace gases at rates ranging from 94 to 313 lbs. per hr., through 2 in. flues cooled by water jackets. It was found to apply equally well to a series of steaming tests made by the *Pennsylvania R. R.* on locomotive boilers with 1¾ and 2 in. flues, to experiments by *Fessenden* in which the water which absorbed the heat was allowed to boil at atmospheric pressure, and by *Jordan*, in which flues of ½ to 2 in. diameter and 3 ft. long, carrying heated air, were exposed to cooling water. By reversing the ratio of gas temperature to wall temperature, the formula can be used for moving gases receiving heat from a flue, as in tests by *Josse* on air at various pressures flowing through a flue .9 in. in diameter and 4 ft. long, and by *Nusselt* on air, CO_2 and lighting gas in .868 in. pipes 1 to 3 ft. long.



RELATION BETWEEN GAS AND FLUE-WALL TEMPERATURES

The effectiveness of the heat absorbing surface, that is, the total transfer, increases with the flow, but the degrees temperature drop and the efficiency are lessened, and the friction head, which is a function of the flow and the hydraulic depth, or ratio of cross-section to perimeter, is increased with increasing rates of flow.

Jordan summarizes the laws of the variation of heat transfer as follows:

(*a*) For a constant mass flow, the transfer is proportional to the temperature difference directly.

(*b*) For a given temperature difference, the rate of transfer increases with the speed by a linear law.

(*c*) For a given rate of flow and temperature difference, the rate of transfer increases with the value of the temperature.

(*d*) The rate of transfer depends on the condition of the surface.

(*e*) The rate of transfer depends on the size of the channel, and the smaller the ratio of area to perimeter, or mean hydraulic depth, the greater the rate of transfer.

ECONOMIZERS, AIR HEATERS AND SUPERHEATERS

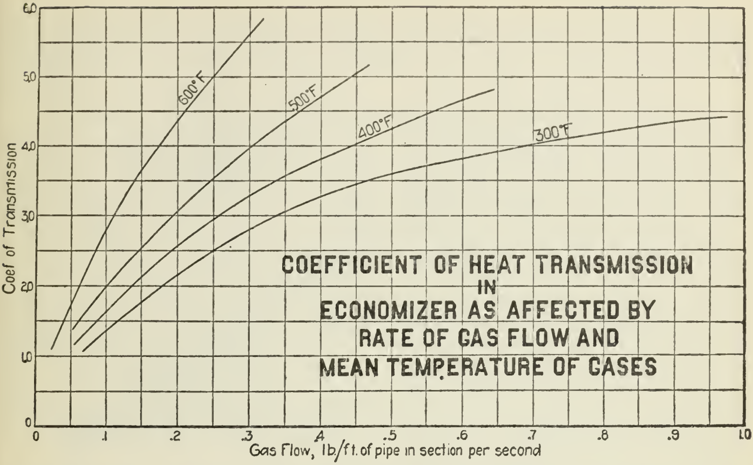
Most **economizers** are arranged for the water to enter all the tubes at the bottom and leave at the top while the gases pass at right angles to them. The equation on page 197 is used in such cases to determine the economizer surface. Where the gases have a great temperature drop the economizer is more efficient if the sections of tubes are connected in series or at least if groups are connected in series with the flow of gas and water in opposite directions, that is, countercurrent. For determining the surface for countercurrent flow, where the temperatures of both fluids change, the differential equation $(T - t)\,RdS = -WcdT$, page 198, can be integrated as follows:

$$S = \frac{Wc}{R}\left[\frac{t_1 - t_2}{(T_1 - t_1) - (T_2 - t_2)}\right]\log_e\left(\frac{T_1 - t_1}{T_2 - t_2}\right)$$

t_1 = water temperature at hot end of the economizer.
t_2 = water temperature at cold end of economizer,
Other symbols as before.

The transfer rate R or coefficient of transmission for economizers is given by *G. H. Gibson* in the curves on page 201, which are based on over 200 tests of standard (not countercurrent) economizers in commercial operation. The transfer rate R is a function of rate of gas flow and of the temperature of the gases in the economizer. The rate of gas flow is plotted as total lb. per sec. through the economizer divided by the number of lineal ft. of tube in one section, *i. e.*, if each section consists of ten 10-foot tubes, there are 100 ft. of tube per section.

While the utilization of the waste heat in the chimney gases for preheating the air supplied to the boiler furnace by means of **air heaters** has been applied to only a limited extent in land plants, it has long had a wide use in steamships, as for example in the *Howden* system. By raising the temperature of the air supplied to the furnace, the combustion temperature is raised and the absorption of heat from the fuel bed by radiation and from the gases by conduction and convection is increased. The overall efficiency is improved, as less heat is lost in the chimney gases. Poorer grades of coal, lignite and peat are burnt more satisfactorily and efficiently. With high grade coals and high rates of combustion difficulty appears to have been experienced in some cases through fusing of the ash and formation of clinker. In internally fired boilers, such as the Scotch marine type, this difficulty is minimized by the cooling action of the surfaces which surround the fire on all sides, and



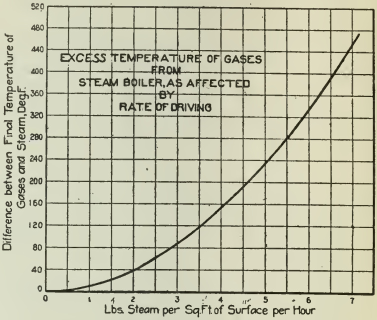
COEFFICIENT OF HEAT TRANSMISSION IN ECONOMIZER AS AFFECTED BY RATE OF GAS FLOW AND MEAN TEMPERATURE OF GASES

sometimes water is also carried in the ash-pit. The practical benefits from the use of air heaters may be illustrated by figures from a test of an air heater installed by the *Underfeed Stoker Co., Ltd.*, in connection with mechanical stokers and Lancashire boilers at a mill in Ireland. The coal was of very low grade and in order to secure better combustion and higher efficiency it was decided to replace the existing water economizer by an air heater in connection with Cochrane exhaust steam feed water heater. The following results were obtained:

Steam pressure, gauge	119.7 lbs.
Feed temperature entering heater	115.5° F.
Do. entering boiler	196°
Gas temperature leaving boiler	677° F.
Do. leaving air heater	368° F.
Air temperature leaving heater	343° F.
Atmospheric temperature	66° F.
Coal burned per hour	1102 lbs.
Evaporation per lb. coal from and at 212° F	9.43
Heating value of coal per lb	11252 BTU.
Overall efficiency	81.2%

The air heater was of a new type in which the air and gases respectively pass at high velocity through the alternate spaces between parallel flat plates. The total surface of the air heater was less than that of the economizer which it replaced.

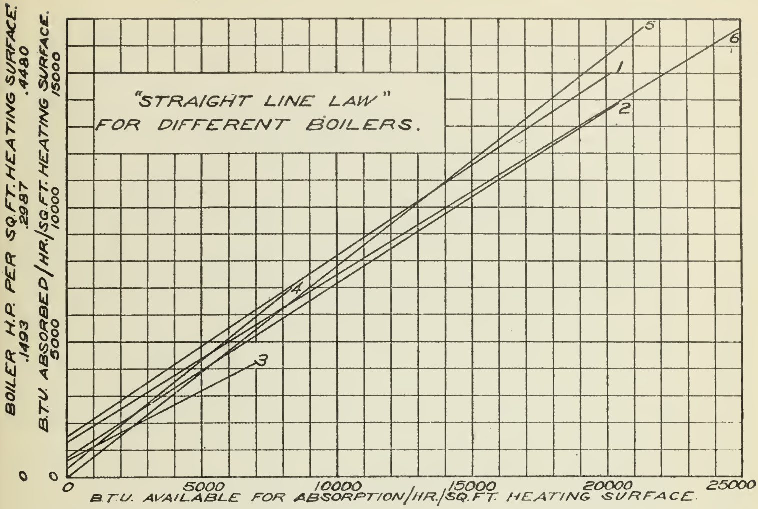
The transfer rate in a **superheater** is about 6 BTU. per hr. per sq. ft. per deg. F. when the furnace gases are at 1000° to 1200° F., and the final steam temperature is 400° to 500° less. Similar rates are obtained in air heaters.



EXCESS TEMPERATURE OF GASES FROM STEAM BOILER, AS AFFECTED BY RATE OF DRIVING

The curve to the right, due to *G. H. Gibson*, shows the difference between chimney gas and steam temperatures for different rates of evaporation in boilers. It is averaged from about eighty tests of directly fired boilers, and can be used to determine roughly the amount of boiler surface required to reduce the gases to within a given number of degrees of steam temperature. As the temperature to which the gases will be reduced by a given amount of surface depends upon the method of baffling, the velocity of gases, the amount of soot, ashes and scale on the tubes, air inleakage, the amount of boiler surface exposed to direct radiation, etc., the curve is only roughly approximate, but where the results from a given boiler do not lie on the curve, it is found that they form a curve that is fairly parallel.

Straight Line Law for Boilers.—*Lucke* points out that in seeking relations between absorption and generation in steam boilers, it is necessary to distinguish between real and apparent heat generation. The apparent generation in BTU. per hr. would be lb. coal fired per hr. multiplied by the heating value per lb. The real heat generated would be lb. fuel fired per hr., times the difference between one and the fraction of fuel lost, times the heating value per pound. The fuel lost would include the carbon in the ashes, in the soot, the unburned gases, carbon monoxide, hydrogen and hydrocarbons, heat required for the evaporation of the moisture in the fuel, and that taken from the hot gases by the walls and the setting between the point of firing and the place where absorption begins. This fraction may be 20%. In considering several reliable boiler tests in which many different kinds of coal were used, he says: "There is no doubt of a linear relation between heat absorbed and heat available for absorption." He gives curves for *Goss*' experiment on a locomotive boiler, the *Bureau of Mines* tests on Heine boilers, *Jacobus's* test at Delray on a Stirling boiler having a heating surface of 23,650 sq. ft., a test of a White automobile flash boiler, and the *U. S. Navy* test of a Hohenstein boiler with liquid fuel. These are grouped in the figure on page 203. The straight line relation was found to hold regardless of boiler structure, kind of fuel, or rate of driving. The only difference is to be found in the two constants of the straight line equation, for which there is an adequate explanation. For all except the White flash boiler, the line does not pass through zero, but shows an absorption when the generation is zero. This must be a measure of the constant ratio of absorption due to radiant heat, whether any hot gas carries heat to the absorbing surface or not. It is natural that this should differ for different boilers, depending on the exposure of the heating surface to the incandescent fuel and to the brick work. The rate at which the absorption increases with rate of evolution is dependent on the proportions of the gas



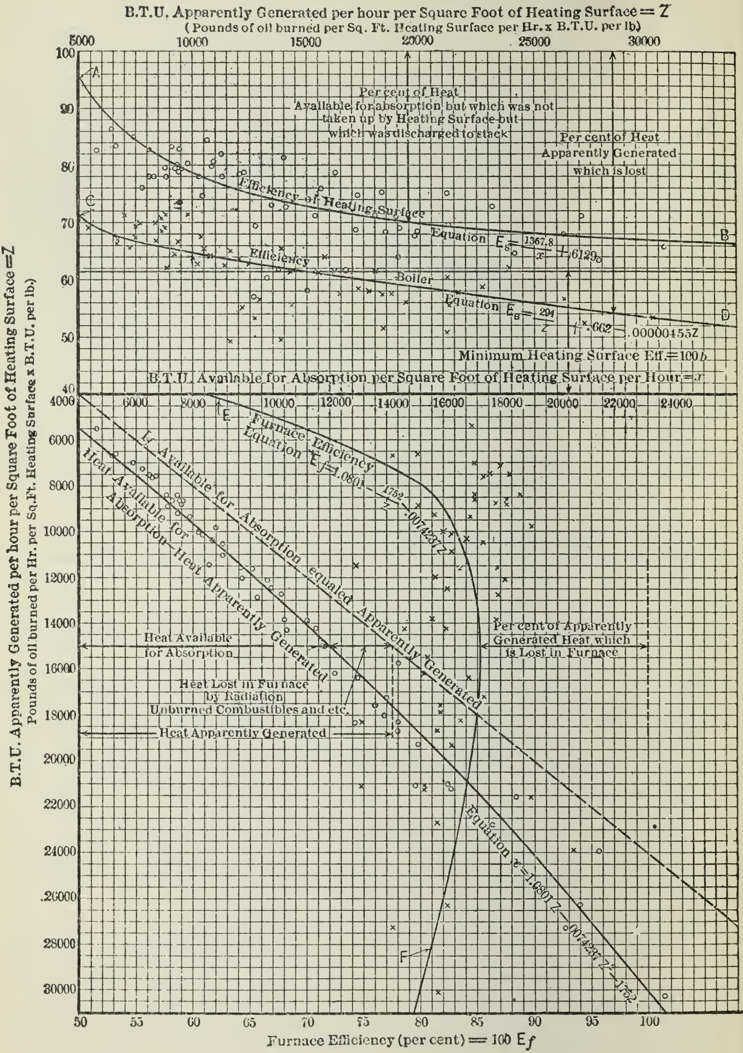
1. Goss' test of a locomotive boiler, including superheater.
2. The same locomotive boiler exclusive of superheater.
3. Bureau of Mines tests of Heine boiler.
4. Jacobus test of Stirling boiler.
5. White automobile boiler.
6. U. S. Navy tests of a Hohenstein boiler.

RELATION BETWEEN THE HEAT ABSORBED AND THE HEAT AVAILABLE FOR ABSORPTION IN DIFFERENT BOILERS

passages, which is again a structural feature. Tests at two loads will determine the straight line, from which any other loads may be picked.

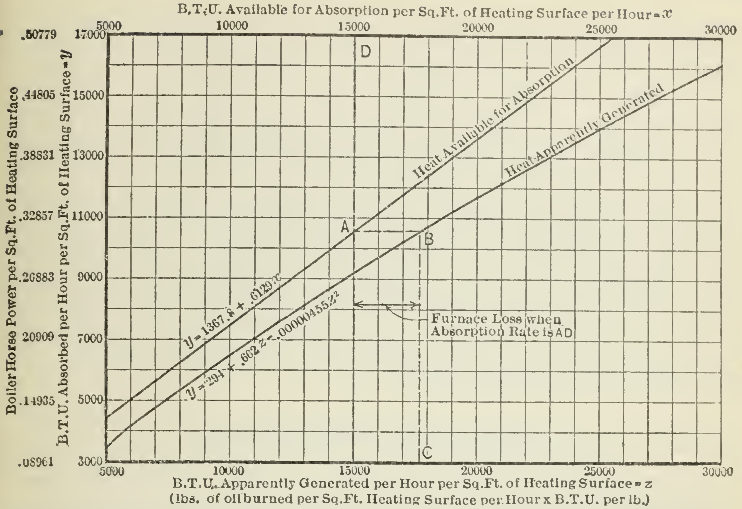
As a general rule, a straight line also results when the heat absorbed is plotted against the heat apparently generated in a boiler furnace, or against the rate of combustion. Should it happen that a curve results, this in itself proves a variable fractional furnace heat loss. The percentage of heat lost in a furnace, etc., usually increases as the load increases, so that the curve bends slightly downward from the straight line, as shown in the figure on page 205, reproduced from *Lucke* for a Hohenstein oil-fired boiler; ordinates are heat absorbed and abscissae for the upper and lower lines are heat available for absorption and heat apparently generated respectively.

A similar straight line relation holds for an economizer. Its rate of heat recovery increases directly with the load on the boiler, with which it is combined. The results of a series of economizer tests are plotted on page 205, by *G. H. Gibson*. The heat recovery with increasing load seems to be less than with decreasing load. This is because its determination depends on measurement of the temperature of the water as it leaves the economizer. There is a lag between the absorption and its measurement, due to the volume of water stored in the economizer. After determining one point by test or computation and drawing a straight line through it and zero, the rate of recovery at all other loads can be read off at once.

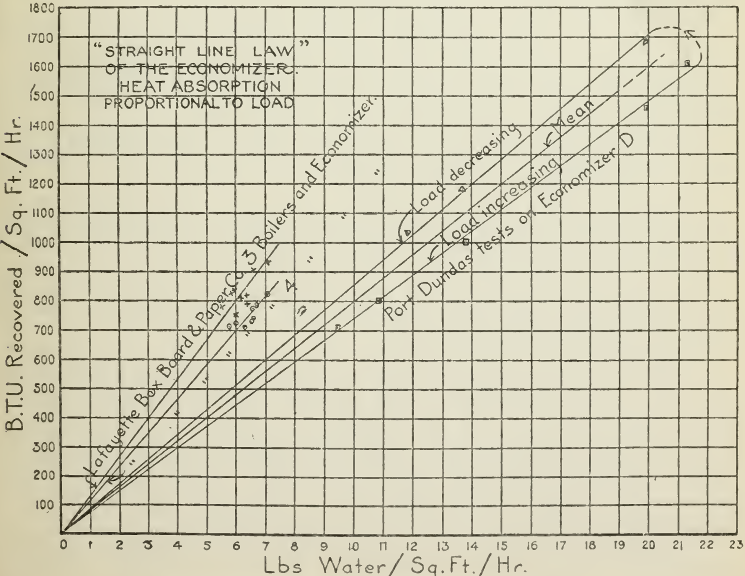


RELATIONS BETWEEN QUANTITIES ENTERING INTO BOILER EFFICIENCY

(See page 206)



RELATION BETWEEN HEAT ABSORBED, HEAT APPARENTLY GENERATED, HEAT AVAILABLE AND HEAT LOST IN FURNACE (OIL FIRED)



"STRAIGHT LINE LAW" OF ECONOMIZER

Lucke, in the curves reproduced on page 204, analyzes the results of a test on an oil-fired Hohenstein boiler. Heating surface efficiency, for practical working ranges of heat generation rates, is a straight line falling with increase in generation. The efficiency of the flue part is independent of the rate of supply of heat. Therefore variations in efficiency are probably due to the fire-box part, which receives radiant heat. The distance between the heating surface efficiency curve *AB* and 100% efficiency represents the flue loss per pound of fuel divided by the generation per pound of fuel or the calorific power less the furnace and setting loss. For these experiments the ratio increases with total generation or rate of combustion. Line *CD* represents overall boiler efficiency. The vertical distance from it to 100% represents the sum of losses in flue as sensible heat and the furnace and setting losses. The vertical distance between *AB* and *CD* represents furnace and setting losses. If the two curves are parallel these losses are constant. If they converge to the right they must decrease with increased generation, and if they diverge the losses increase with increased generation. In this particular case the losses first increase and then decrease, and are plotted in line *EF*. The other curves are as discussed before.

IMPROVING ABSORPTION

The following statements, by the *Bureau of Mines,* are based on numerous investigations:

"A boiler that has its heating plates arranged in such a way that the gas passages are long and of small cross-section is more efficient than one in which the gas passages are short and of large cross-section.

"If the same weights of gas at the same initial temperature are passed through a 2-in. and a 4-in. flue, both flues having the same length, the 2-in. will absorb more heat than the 4-in. flue, although the 4-in. flue has twice as much heating surface as the 2-in. Locomotive boilers are more efficient than stationary boilers at the same rating, for this reason.

"To increase the efficiency of water tube boilers, insert baffles in such a way that the heating surfaces are arranged in series with reference to the gas flow, thus making the gas passages longer.

"In multi-tubular boilers, the efficiency increases as the diameter of the tubes decreases, and as the length of the flue increases. In water-tube boilers, it increases as the cross-section of the gas passages between individual tubes decreases, and as the length of the passages increases.

"As the velocity of the gases over a heating plate increases, the true boiler efficiency at first drops, and then, after the gases exceed a certain velocity, it remains nearly constant."

Experiments on a laboratory boiler showed that as the initial temperature of the air was increased, the rate of absorption increased, but not in proportion to the temperature. This indicates that the density of the air, which varies inversely with the temperature, influences heat absorption. When the initial temperature of the air was constant, the quantity of heat absorbed increased almost directly with the weight of air passing through the boiler. This fact is important for boiler practice. When the initial temperature was constant, as the quantity of air increased, the temperature of the air leaving increased to a certain constant temperature.

It may be said that if the lengths of the flues are constant, the true boiler efficiency drops when the diameter of the flues is increased. An exact relation cannot be given. If the diameter of the flues is constant, the true boiler efficiency increases with the length of the flues, but not in direct ratio.

It is not area, but arrangement, that makes the heating surface efficient. Increasing the length beyond a certain reasonable limit does not pay.

In water tube boilers with horizontal tube bank, the bottom row of tubes does far more work than any other row, and from the bottom row up to the top, the amount of work done by the tubes decreases rapidly.

The application of the principles of heat transmission offers an excellent opportunity for economic improvement in the steam boiler, as well as in steam plant design. It seems feasible to increase the capacity of boilers several times, and by properly arranging the heating surfaces, to raise efficiency several per cent. at the same time. Increasing the capacity reduces the first cost of installation, and consequently lowers the interest charge. Increasing the efficiency reduces the coal bill.

Summarized,

The capacity of a boiler can be increased by forcing a greater weight of gases through it.

The efficiency of a boiler as a heat absorber can be increased by arranging the heating surfaces in such a way that the gas passages are long and of small cross-section, so that they have a small "hydraulic mean depth."

Trinks says that if a flue carrying hot gases through a boiler is provided with a central core of refractory material, the latter becomes hot and radiates all the heat which it receives from the gases directly to the flue. The surface of the core has become additional heating surface. This shows how radiation can be used to improve boiler absorption.

In 1905 Messrs. *Stott* and *Finlay* made complete tests on a 600 H. P. B. & W. boiler at the Interboro Rapid Transit Co. for a period of over five months. The boiler was equipped with a Roney stoker. In 1907 they placed another Roney stoker in the rear of the setting, and ran complete tests over a period of two months. A baffle was placed above the bottom row of tubes, parallel with them, extending from the first baffle to the rear header.

The upper curve in the chart on page 209 shows the relation between boiler horse-power developed and the quantity of heat presumably liberated from the furnace per hr. and delivered to the boiler. The quantity of heat is computed from the weight of coal fired per hr. and the heating value of 1 lb. of coal. This is used in preference to the rate of combustion, because the effect of a difference in the quality of coal is thereby eliminated. The tests with a single stoker are represented by the hollow triangles, while the tests with the double stoker are represented by the solid triangles. All the tests lie fairly close to the straight line, indicating that the output of the boiler increased in direct proportion to the quantity of heat delivered to it.

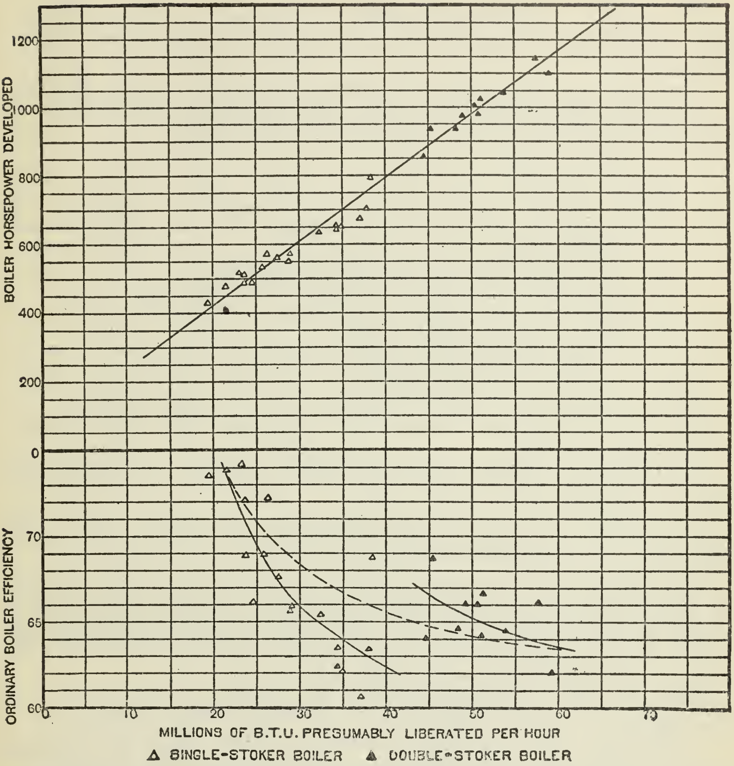
The lower curve is intended to show the effect of heat delivery rate on boiler efficiency, that is, combined efficiency of the boiler and furnace. It is difficult to draw a single curve through the points representing the single stoker and the double stoker tests. As the quantity of heat liberated increases, the efficiency of the boiler with a single stoker shows a tendency to drop 4 or 5% below that of the double stoker. One cause of this is undoubtedly the fact that the fuel on the original front stoker does not burn completely, on account of the small combustion space above that stoker. The addition of the rear stoker more than doubled the combustion space. This produces better combustion. Another cause is probably that a greater proportion of the heat is received by radiation. It is due to these two that with heavy loads on the boiler the efficiency is higher when two stokers are used. The point to be emphasized is that any fluctuation in the overall efficiency is due more to variation in the efficiency of the furnace than to that in the boiler as a heat absorber. The latter efficiency seems to be practically constant, and independent of the rate of working. Another cause of the drop in efficiency shown in the tests of the single stoker below that shown by the tests of the double stoker is that part of the heat liberated on the rear stoker is absorbed by the boiler by radiation and conduction through the tile roof, so that the gases are not as hot when they enter the tubes as are the products of combustion from the front grate. Any heat that may be given to the boiler by radiation is that much clear gain.

In 1903, *Abbott* and *Bement*, of the Commonwealth Edison Co., Chicago, made a comparative test on a Heine boiler which they baffled in three different ways, the standard single pass, a double pass and a triple-pass arrangement. To form the double-pass setting, a single horizontal baffle was inserted between the tenth and 11th horizontal row of tubes. The top baffle was shifted forward so that the gases left the tubes at the rear instead of at the front. The gases came in contact with only the rear one-fifth of the steam drums. To obtain the triple-pass setting two horizontal baffles were inserted in the standard setting. The first was laid above the 8th row of tubes, and the second above the 14th, the total height of the boiler being 17 rows. The boiler with the standard baffling showed an ordinary boiler efficiency of 57%, the double-pass an efficiency of 62%, and the triple-pass boiler an efficiency of 67%. With the same total pressure drop, the capacity obtained with the double-pass boiler was about 5% higher than that obtained with the standard boiler. With approximately the same total pressure drop, the capacity of the triple-pass was somewhat higher than that of the standard one.

The addition of one or two horizontal baffles re-arranges the heating surfaces of the tubes. It places sections of the tube surfaces in series. The section of tubes which the gases enter first was made considerably larger than the succeeding section or sections for the reason that the gases when entering this first section are much hotter and therefore occupy a much larger volume than when passing through the following sections.

The flue gas temperatures reported in these tests are all too low because the thermometer bulbs were not screened from radiating heat to the cold surfaces of the boiler and breeching. As the thermometers were inserted in similar places in the setting, the temperatures can be used for comparison. The average flue gas temperatures were 635°, 550°, 470° F. for the single, double and triple-pass boilers respectively. Any further increase of the length of gas passage would reduce the flue gas temperature very little, and it would hardly pay to lengthen the path of the gases more than by the double or triple pass. Although the figures in the above are to the contrary, it cannot be expected that the increase in efficiency of the triple-pass boiler over the double-pass boiler would be as great as the increase in efficiency of the double-pass over the single-pass boiler, and the gain would be less for each succeeding increase in the length of the gas passage.

See also under "Baffling," page 211.



SINGLE AND DOUBLE STOKER BOILERS COMPARED AS TO CAPACITY AND EFFICIENCY (ORDINARY OVER-ALL EFFICIENCY FROM COAL TO STEAM)

HEATING SURFACE AND BOILER CAPACITY

Those parts of the boiler shell, flues or tubes which are covered by water and exposed to hot gases or to radiation constitute the heating surface. Any surface having steam on one side and exposed to hot gases on the other is superheating surface. The *A. S. M. E. Boiler Testing Code Committee* recommends that the extent of the heating surface be measured on the side next to the gases.

A boiler horse power is defined by the Committee as the equivalent evaporation of 34.5 lb. of water from and at 212° F. per hr., equivalent to 33,479 BTU. per hr.

The original definition by the *Committee of Judges* at the *Centennial Exposition* was the evaporation of 30 lbs. of water from an initial feed temperature of 100° F. to steam at 70 lb. gauge pressure, equivalent to 33,243 BTU. per hr.

The factor of evaporation is the ratio of the heat required to generate 1 lb. of steam under actual conditions to that required to generate 1 lb. of steam from and at 212 degs. F. The factor of evaporation

$$F = \frac{H - h_f + sS}{970.4}$$

H = total heat of saturated steam above 32° F. at boiler pressure, BTU per lb.,
h_f = heat of the water at feed water temperature
= approximately number of degrees above 32° F.,
s = specific heat of superheated steam (see page 228),
S = degrees of superheat, if any,
= temp. difference between the superheated steam and saturated steam at same pressure,
970.4 = latent heat to evaporate 1 lb. steam from and at 212° F.

The actual evaporation multiplied by F gives the "equivalent evaporation from and at 212° F."

The commercial rating of boilers is entirely arbitrary. It is customary to rate a stationary boiler on the basis of 10 sq. ft. of heating surface per boiler horse-power.

The capacity of a boiler usually designates its maximum capacity for evaporation. It is expressed ordinarily in terms of % of the builder's nominal rated horse-power.

The number of sq. ft. of heating surface required per boiler HP. decreases as the initial temperature of the gases and the effective pressure drop increase. "Broadly stated, the evaporative capacity of a given well-designed boiler, that is, the boiler horse-power it is capable of producing, is limited only by the amount of fuel that can be burned under it."

However, there are limiting features that must be weighed against the advantages of high capacities developed from small heating surfaces.

1. Efficiency. As the capacity increases, there will in general be a decrease in efficiency. This loss above a certain point makes it inadvisable to try to secure more than a definite boiler horse-power from a given boiler.

2. Grate surface possible and practicable. All fuels have a maximum rate of combustion, beyond which satisfactory results cannot be obtained, regardless of the draft available. Such being the case, added capacity can be obtained only by addition to the grate surface. The grate surface is limited to a practicable handling size, and by available space.

3. There is an enormous loss in draft when it is attempted to force an abnormal quantity of gases through the boilers.

4. Feed water. When the boilers are abnormally overloaded, there is an increased tendency to foaming and priming and increased danger from overheating of the metal because of insufficient circulation or because of scale.

It is, however, possible to force boilers at high rates without a greatly increased moisture content in the steam, as witness locomotive and marine boilers, which have three times the capacity of stationary boilers as ordinarily used.

THE BOILER SETTING

Boilers of widely-differing patterns have shown equal efficiencies in trials. It is coming to be the general belief that peculiarities of tube arrangement in boilers count for less than proper furnace design and proper baffling.

Furnace and Combustion Chamber.—As discussed under the section on page 109 the furnace chamber and the combustion chamber must be ample in size, so that the gases are not cooled before they have had time for combustion, and so that the gases and air are properly mixed. In a return tubular boiler installation, the cooling effect of the boiler shell on the gases, though not negligible, is much less than it is often thought to be, inasmuch as the area exposed is not more than that of 8 or 9 tubes. The results of a series of tests by the *Bureau of Mines* show clearly "that at a given rate of firing, as the air supply is increased, the time, and therefore the volume of the combustion chamber, requisite for complete combustion decreases rapidly."

Baffling.—The *Bureau of Mines* ran tests to determine whether with horizontal baffling, giving a larger combustion space, a high volatile coal could be burned with good results, and whether with this baffling, Pocahontas coal could be burned as economically as with the standard vertical baffling. In three series of tests on a B. & W. boiler the baffling was arranged as follows:

1st series: Standard vertical baffling. There were four tests with Clinchfield, and three with Pocahontas coal.

2d series: Two-pass horizontal baffling; one row of tubes below the lower baffle, five rows of tubes between the first and second baffles, three rows of tubes below the top baffle. A space behind the bridge wall served as a combustion chamber. The drum surfaces were not used as heating surfaces. There were four tests with Clinchfield and three tests with Pocahontas coal.

3d series: Three-pass horizontal baffling. Two rows of tubes were below the first baffle, three rows between the first and second baffle, two rows between the second and third, and two rows below the top baffle. The drums were used as heating surface. There were three tests with Clinchfield coal, and two tests with Pocahontas. The table gives a summary of the results obtained.

Lb. Water Evaporated per Lb. Coal:

	Standard Baffle	2-Pass Horz. Baffle	3-Pass Horz. Baffle
Pocahontas Coal	7.95	8.54	8.83
Clinchfield Coal	7.49	8.18	8.52

The horizontal baffling shows a much better evaporation with both the Pocahontas and Clinchfield coals. The improvement is greater with the Clinchfield coal. The three-pass horizontal baffling gave the highest evaporation. The two-pass gave the highest horse-power with the draft available. The two-pass boiler had a slightly lower draft loss through the boiler than did the vertical baffling, while the three-pass boiler had a slightly greater draft loss.

The setting used in the St. Louis tests by the *Bureau of Mines* differed in that the gases passed twice through the tube space, without passing under the steam drum. This was accomplished by a special horizontal baffle between the two regular baffles on the Heine boiler. The boiler with this setting showed the greatest heat absorption. Comparing this boiler and one of the standard setting, for a combustion chamber temperature of 2100° F., the standard boiler showed a temperature reduction of 1510°, and the special boiler 1610°. If the temperature of the steam in both boilers is taken as 350° F., the available difference is 2100 — 350, or 1750°, therefore the percentage of available heat used by the standard boiler is 1510/1750, or 86.3%, while that used by the boiler with the special horizontal baffle is 1610/1750, or 92% of the available heat. Averages show that the standard boiler had a combined efficiency of 67.4%, and the one with special horizontal baffle had a combined efficiency of 68%.

See also under "Improving Absorption," page 206.

Osborne Monnett says that in solving the smoke problem in Chicago he was often forced to employ horizontal baffling. Tests proved that efficiency and capacity were not lost. With horizontal baffling there is usually a greater draft loss, and the factor of available draft must be given consideration.

Hays says that short-circuiting of the gases is a common fault, and exists to a greater extent than most engineers imagine. "The baffling always should be inspected when the boiler is shut down for cleaning and repairs."

Baffles should be examined for the smallest cracks and these cemented tightly. Concentration of flow gradually forces a larger opening until failure of the baffle results. The installation of pyrometers in the top of the last pass, fitted with recording devices if possible, is a ready safeguard against operating for any length of time with the baffles out of order. The effect of a broken baffle is shown by the temperatures taken on a 500-hp. Stirling boiler. The temperature over the fire was 2462° F. With baffles in good shape, the temperature at the first pass was 1148°, and at the top of the last pass 545°. With a defective baffle the temperature at the top of the first pass dropped to 662°, due to non-circulation of gases at this point, while that at the top of the last pass was 1778°. The efficiency had dropped from 78.8 to 28.2%. A hole was discovered in the center of the first baffle 32 by 28 in.

Furnace Walls.—Commonly there is 4% heat lost through the furnace walls. An air space has sometimes been used. The *Bureau of Mines* points out that so far as the loss of heat is concerned, a solid wall of any ordinary material is preferable to a hollow wall of the same total thickness, especially if the air space in the hollow wall is near the furnace side. The air in the air space is a poor conductor, but the heat passes through it rapidly by radiation. When heat at low temperatures is to be insulated, use an air space. When heat at high temperatures is to be insulated, as in a furnace, use solids of poor conductivity. Where walls are built in two parts, to prevent cracks from expansion of brick-work on the furnace side, fill the space with solid loose material. Brick or sand offers a higher resistance than air. The heat loss will be reduced 50%.

The *Bureau of Mines* at St. Louis enclosed a boiler setting entirely in an airtight iron casing. The purpose was to determine:

1. Whether air spaces in the side walls reduced the radiation losses, and therefore increased the efficiency.
2. Whether, by preventing air leakage, the heat loss in the chimney gases was reduced and the efficiency raised.

Nothing was gained in efficiency. What was gained by the air-tight setting was perhaps lost by increased radiation. The double fire door exposed too much iron surface directly to the fire, and thus increased the radiation from the furnace front. The temperature of the sheet-iron casing on the sides of the boiler often rose above the boiling point of water, indicating that too much heat passed through the air spaces in the side wall.

Arches, Piers and Wing Walls.—An ignition arch, as used with chain grates or overfeed stokers, is substantially a heat mirror. It receives heat from the rear and highly-heated part of the firebed and furnace brick-work and radiates it to the front where the fresh coal enters, thus assisting in the distillation and ignition.

The tar globules and small particles of solid carbon move with the gases through the furnace and combustion chamber. Products of combustion form around their outer surfaces and tend to insulate them from coming in contact with oxygen. Commotion in the gas stream will produce a scrubbing action which will remove the insulating film of products of combustion. The insertion of brick piers in the path of the gases, or changing the cross-section of the gas passages, so that the stream expands and contracts, induces relative velocities which bring fresh oxygen to the combustible particles. In other words, rapidity of combustion is improved by turbulence.

The *Bureau of Mines* at the St. Louis test developed a mixing arch of blocks 18 x 12 x 6 in. of the best fire-clay obtainable. The wall was in three portions. The bottom consisted of 7 blocks set up vertically and forming pillars for an arch of 6 similar blocks laid diagonally across. The space between the arch and the tile-roof was filled completely with ordinary fire-brick of good grade. To further mix the gases, 6 additional large blocks were set up vertically back of the mixing wall, and immediately in front of the vertical opening between the pillars. This construction lasted 4 mos., while the boiler was run below rated capacity. Later when very hot fires and high capacity tests were run, the mixing walls lasted from two weeks to a month. The following are representative temperatures at five places in the furnace:

Temperature of the fuel bed	2470° F.
Temperature above the fire	2586° F.
Temperature over the bridge wall	2826° F.
Temperature at base of mixing wall	2989° F.
Temperature in rear of combustion chamber	2447° F.

Just how the overall efficiency was affected by this mixing structure was never determined. It was the opinion among the experimenters that it was increased from 1 to 3%.

Ash-Pits.—The following three points should be observed in the design of ash-pits.

Capacity.—The ash-pit should accommodate a 20 hr. run. This avoids the handling of ashes at night. Pits of 12 to 14 hr. capacity are usually available. Determine the maximum amount of fuel that can be burned on the grates. The maximum percentage of refuse times the hourly fuel consumption is the refuse per hour. It is safe to provide for 10% of high-grade Atlantic Seaboard coals as refuse, 15% of Pittsburgh coals, 20% of Illinois and Indiana coals, and 40% of Iowa and Southwestern coals. 1 cu. ft. of ash weighs 40 to 50 lb.

Ease of Cleaning.—It is important that the ash-pits be readily cleaned, or the work will be shirked and the grates damaged by allowing the ash-pit to become overfilled. The discharge door should be at a convenient height, and there should be room for using the shovel and the hoe. Where hoppers are used, the valves should be reached easily from the floor level.

Maintenance.—Concrete and brick-lined ash-pits are most desirable. Never permit the ash to pile against the doors or front. This will warp them.

REFRACTORIES AND FIRE-BRICK

Fire-brick are manufactured from natural fire clays composed principally of alumina and silica and of two kinds, plastic or soft clay, and flint or hard clay. Flint clay has little binding power within itself. The best binder is the plastic clay. Bricks for different purposes are mixtures of different percentages of different clays. The physical characteristics of a fire-brick apparently determine its qualities so far as boiler furnace work is concerned and its chemical characteristics can practically be ignored.

The quality of fire-brick ordinarily is judged by the following:

1. **Plasticity**—Until recently, the melting point of brick was considered the most important characteristic in judging suitability of fire-brick for boiler settings. Experience has shown that the plasticity under a given load should be the real basis. The tendency to become plastic shows at a temperature much below the melting point. The allowable plastic or softening temperature will naturally be relative, and dependent upon the stress to be endured.

Steam says that it is probable that practically all fire-brick on the market, if tested under the stress met with in arch construction, would show this critical plastic temperature below 2400° F. That an arch will stand for long periods under furnace temperatures above 2400° is due entirely to the fact that its temperature as a whole is far below the furnace temperature, and only the 10% or so of its cross-section nearest the fire approaches the furnace temperature.

The *Bureau of Standards*, giving a test for determining plasticity, says "when subjected to load tests in a manner substantially as described, at 2462° F., and under a load of 50 lb. per sq. in., a standard fire-brick tested on end should show no serious deformation, and should not be compressed more than 1 in., referred to the standard length of 9 in." Testing the brick on end may be criticised for boiler purposes, because it is a compression test, and subject to errors from unequal bearing surfaces, causing shear. A better method, recommended by the highest authorities in ceramics, is a test as a beam subjected to its own weight and not on end. It takes into account the tension element which is important in arch construction.

Steam says that the plastic point under a stress of 100 lb. per sq. in., which is the average maximum arch stress, should be above 2800° F., and must be above 2400° to enable the brick to be used with any degree of satisfaction.

2. **Fusing Point** is important only as indicating a high critical temperature of plasticity.

3. **Expansion** in connection with hardness, is a measure of the physical movement of brick as affecting a wall and producing cracking. Lineal expansion should not exceed .05 in. in a 9-in. brick at 2600° F.

J. W. Mellor points out that brick after being fired does not contract exactly to its original volume; it may be smaller or larger. Therefore, if brick has been improperly burned, when it is again heated there will be superimposed on the ordinary thermal expansion a so-called after-expansion or after-contraction. Doubt is therefore cast upon the accuracy of former determinations of expansion for fire-bricks. His experiments show that the expansion coefficients of fire-clay and silica brick decrease with temperature rise. An average coefficient of expansion for fire-brick would be .00,000,5 per degree C. or .00,000,27 per degree Fahr.

66 bricks each 2½ in. high with a coefficient of .00,000,27 would expand 1 in. when heated to 2200° F. Expansion is one of the chief causes of failure of fire-brick arches.

4. **Compression** is measured as the load necessary to cause crushing at the center of a 4¼ in. face by a steel block 1 in. square. A suggested standard is that the brick should show signs of crushing at 7500 lb.

5. **Hardness** is the second reason for the failure in fire-brick arches. The harder a brick the greater its tendency toward "spalling." The bricks are subjected to gases at widely varying temperatures and hence to unequal expansion and to localized stresses, causing a hard, brittle brick to fail. Fur-

thermore, joints are rarely perfect, causing overloading at the points of contact between bricks. Hardness is relative and is rated on an arbitrary scale.

6. **Size of Nodules** is the average size of flint grains when the brick is carefully crushed. Small size is that of anthracite rice, large size is that of anthracite pea.

7. **Ratio of Nodules** is the percentage of a given volume occupied by flint grains. High, 90 to 100%. Medium, 60 to 90%. Low, 10 to 50%.

The above characteristics are suggested for arch brick. For side-wall purposes the compression and hardness limit may be raised considerably, and the plastic point lowered.

Steam says that the value of fire-brick can only be considered from a relative standpoint. Generally speaking, what are known as first-grade fire-brick may be divided into three classes, as follows:

Class A. For stoker-fired furnaces where high overloads or other extreme conditions of service may occur.

Class B. For ordinary stoker settings where no excessive overloads will occur, or for hand-fired furnaces with high rates of driving.

Class C. For ordinary hand-fired settings which will be overloaded at rare intervals and for short periods only.

The table below gives the characteristics of these three classes. The hardness of the brick in general increases with the poorer qualities. Provided the hardness is sufficient to enable the brick to withstand its load, additional hardness is a detriment rather than an advantage.

APPROXIMATE CLASSIFICATION OF FIRE-BRICK

Characteristics	Class A	Class B	Class C
Safe fuse point, degs. F.	3200–3300	2900–3200	2900–3000
Compression, lbs.	6500–7500	7500–11,000	8500–15,000
Hardness, relative	1–2	2–4	4–6
Size of nodules	Medium	Medium to medium large	Medium to large
Ratio of nodules	High	Medium to high	Medium low to medium

A fracture gives an approximate determination of the quality of fire-brick. Where it is open, clean, white and flinty, the brick is probably of good quality. If it has the fine uniform texture of bread, the brick is probably poor.

Failures of brick-work from chemical disintegration are found only occasionally, and principally in bricks which contain a high percentage of iron oxide.

When the grade of brick best suited to the service of the boiler has been selected, proper laying is the important item. It is probable that more setting difficulties arise from the improper workmanship in the laying up of brick than from the raw material. In setting up fire-brick linings, a fire-clay wash is used in the joints. It is not a binder, but merely a filler. The bricks should touch each other, that is, the fire-clay mortar should be as thin as possible.

So-called "plastic fire-brick" is proving very satisfactory, overcoming the difficulty due to expansion. It is a mixture of clays which have been submitted to a special mechanical treatment to give a negligible expansion coefficient. The plastic lining material is placed by hand and pounded to make it compact. A slow fire for about 5 hr. burns it in place and the resulting structure is monolithic, including front arch, side walls, bridge wall and combustion chamber walls.

Boiler and Pipe Coverings.—*Gebhardt* states that the loss of heat from bare pipes and drums may be taken roughly at 3 BTU. per sq. ft per hr. per deg. F. difference in temperature, the actual loss depending upon the diameter and position of the pipe and its exposure to air currents. By the use of good commercial coverings, 75 to 90% of this heat loss may be prevented. The following results of tests on pipe coverings have been collected by *Paulding:*

Covering	Diam. of Pipe, in.	Thickness of Covering	Steam Temp., F.	Air Temp., F.	BTU per sq. ft. of pipe per hr.	Do., per deg. temp. difference
Hair felt	2	.96	302.8	71.4	89.6	0.387
Hair felt	8	.82	348.3	69.0	117.9	0.422
Mineral Wool	8	1.30	344.1	58.3	81.3	0.284
Asbestos sponge felted	2	1.125	364.8	60.7	145.0	0.477
Asbestos sponge felted	10	1.375	364.8	62.8	85.0	0.248
Magnesia	4	1.12	388.0	72.0	147.0	0.465
Magnesia	8	1.25	344.1	66.3	106.6	0.384
Magnesia	10	1.19	365.2	66.0	103.0	0.347
Asbestos air cell	4	1.12	388.0	72.0	166.0	0.525

SOOT

As found in steam boilers, "soot" is little like lampblack, and often it is not even black. Even if ideal conditions of combustion are continuously maintained, so that no amorphous carbon is formed, the tube surfaces will rapidly become covered with an insulating coating, formed largely of ash. The deposit may range in color from gray, green, red and brown to white.

In tests made by the *U. S. Bureau of Mines* at the St. Louis Exposition, the weight of earthy matter in the refuse from a test was usually 15 to 20% short of the amount indicated by a chemical analysis of the coal. This difference is accounted for by the quantity of refuse and ash carried by the current of gas into the combustion chamber and up the stack.

This deposit often fuses at low temperatures, and the effect of the coating is cumulative, first insulating the tubes and causing the chimney gas temperature to rise. Then, due to the higher temperature, it fuses and forms a more impenetrable coating, with consequent still higher gas temperature. Fused soot has even been known to bridge over between the tubes, thus choking the draft and reducing the capacity. Soot is formed in all boiler installations, no matter what the fuel, whether it be hard or soft coal, oil, blast-furnace gas, or refuse.

The higher the draft intensity, the greater will be the amount of soot.

The combustible particles of the soot are due to incomplete combustion; the draft may even carry small particles of coal through the combustion chamber unignited. If the combustion chamber is small and the temperature low, the hydrocarbons will not burn completely therein, and small particles of carbon will pass on with the gases.

The rate of soot accumulation depends on the coal. Instances have been known where 1 in. accumulated on top of tubes in an 8 hr. run.

All boilers should have the soot blown off the tubes every day. Firetube boilers should have the tubes scraped twice a month, to remove tarry soot. If a furnace never smokes, there may be little carbon soot on the tubes, but there can be a great deal of fine ash, even from anthracite.

The *Vulcan Soot Blower Co.* says: "Figures from one of the largest electric light plants in the country, regarding a new and perfectly clean 600 HP. horizontal water tube boiler operated at 150% of rating show that the uptake temperatures for the first day were an average of 550° F., while on the fifth day the average uptake temperatures had risen to 650° F.

"The increase of 100° in flue gas temperature in four days represents an increase in coal consumption of approximately 5%. These boilers were not cleaned, and the figures given are a good indication of the rapidity with which soot insulates the tube surface and cuts down economy, as the time a boiler has been in service increases.

"Tests made by *Mr. A. W. Conklin*, Combustion Engineer, showed the following temperatures:

	Near Bottom 1st Pass	Top 1st Pass	Bottom 2d Pass	Top 3d Pass
Hand blown........................	1697	954	727	618
Cleaned by Steam Blower.............	1691	934	649	527

Gas temperatures were read at the points indicated in a horizontal water tube boiler. In the first case the tube surface was blown thoroughly by a steam lance and the average temperature of the flue gas was 618°. In the second case with the steam blower in use, the exit temperature was 527°, the difference in temperatures representing between 4 and 5% gain.

"The following figures relate to flue gas temperatures in Stirling boilers in two plants, one, a large industrial plant; the other, a hotel in Chicago. In the first the decrease in average flue gas temperature was 81° with a slightly higher furnace temperature. In the second the average temperature of the chimney gases fell 164°, the furnace temperatures being practically identical. The increases in heat absorption in favor of the mechanically cleaned boilers were 8.6% and 12.46% respectively.

"On a test recently made on a 300 HP. B & W boiler in a large gas works, to determine the efficiency of mechanical blowers, it was found that by using the blower every six hours, instead of once in every 24, as had been the practice with the hand jet, the average stack temperatures were reduced 110°, the boiler efficiency increased about 4%, and there was a saving of six hours' labor of one man each 24 hours operation."

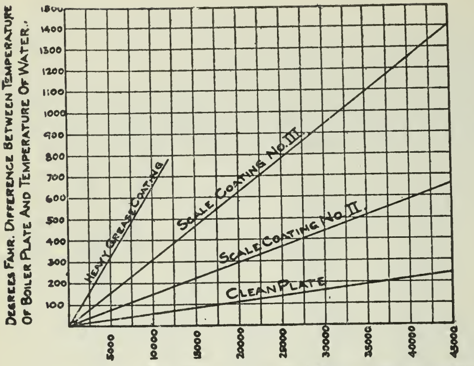
SCALE

Steam says that in view of the present day tendency toward large size boiler units and high overloads, the importance of the use of pure water for boiler feed purposes cannot be overestimated.

With the exception of rain water, melted snow and condensate, practically all water supplies used for boiler feeding are contaminated to a greater or less degree with mineral salts, vegetable matter or acids which will corrode the boilers or deposit scale therein.

Reports of boiler inspection and insurance companies show that more than half of the boilers inspected by them are affected by burned plates, defective tubes, leakage around tubes, leakage at joints, incrustation and scale, internal grooving and internal corrosion, all of which can positively be traced to the feed water.

Effect of Scale on Heat Transmission.—An amount of scale which was harmless at gentle rates of steaming becomes dangerous when the boilers are driven so hard that the layer of scale next to the metal is dried out, becoming an excellent heat insulator and exposing the metal to overheating and burning. The rise in temperature of the metal, due to coatings of scale, is shown in the chart on page 218, taken from a report by *E. Reutlinger*.



EFFECT OF SCALE ON HEAT TRANSMISSION

Professor Schmidt, of the University of Illinois, from a series of tests of locomotive tubes covered with different thicknesses of scale up to one-eighth inch, draws the following conclusions:

1. Scale varying in thickness up to ⅛ in. causes a heat loss varying from insignificant amounts up to as much as 10 or 12%.

2. The loss increases somewhat with the thickness of the scale.

3. The mechanical structure of the scale is of as much or more importance than the thickness in producing this loss.

4. Chemical composition, except in so far as it affects the structure of the scale, has no direct influence on its heat-transmitting qualities.

In confirmation of this it is stated that results of 120 tests by the *Illinois Central Railroad* showed that the miles run per ton of coal were 11% greater during the month after cleaning the boiler than during the three months before cleaning.

E. W. Fiske states that as a result of tests made for three months previous to and three months after scale was removed from a boiler, it was found that the result at the coal pile was 10% in favor of the clean heating surface.

The cost of using unsoftened scale-forming water in boilers is represented principally by:

1. The extra coal consumed.

2. The cost of extra boilers to make up for the limitations on boiler capacity imposed by scale-forming water.

3. The cost of extra boilers in order to provide for standby in cleaning.

4. The cost of cleaning, retubing and repairing boilers.

5. The cost of firing boilers put out of service for repairing and cleaning.

6. The depreciation on boilers, of which the life is greatly shortened by corrosion, pitting, cleaning, expansion and contraction strains and other evil effects of scale-forming feed water.

7. Cost of city water where a cheaper supply could be used were it not for scale-forming matter contained.

8. Cost of boiler compounds.

Expressions of hardness of water are as follows:

1 American degree of hardness = 1 grain $CaCO_3$ per U. S. gallon.
1 British degree of hardness = 1 grain $CaCO_3$ per Imperial gallon.
1 French degree of hardness = 1 part $CaCO_3$ per 100,000.
1 German degree of hardness = 1 part CaO per 100,000.
1 grain per U. S. gallon = 1.2 grains per Imperial gallon.
= 1.712 parts per 100,000.
= 17.12 parts per 1,000,000.
= $\frac{1}{7}$ pound per 1000 U. S. gallons.

See table of conversion factors, page 249, for weights and volumes.

Harmful Substances in Boiler Feed Water.—The mineral and organic substances present in natural water supplies vary greatly in their relative proportions, but are principally comprised under the carbonates, sulphates and chlorides of lime, magnesia and sodium, iron and aluminum salts, silicates, mineral and organic acids, and the gases oxygen and carbon-dioxide. Scale is formed from the carbonates and sulphates of lime and magnesia, and from the oxides of iron, aluminum and silicon. Corrosion is caused by the chlorides of magnesium and sodium, and by mineral and organic acids, and appears to be largely conditional upon the presence of free oxygen.

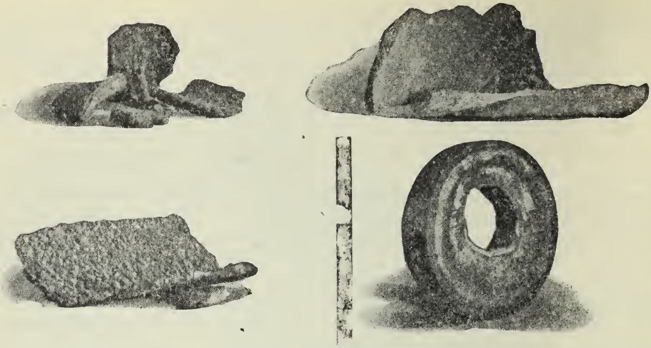
Calcium Carbonate.—Calcium is found in nearly all natural water supplies. Calcium oxide, known as quicklime, combines with water to form calcium hydroxide, or hydrate, known also as caustic lime or slaked lime, and soluble in water to form lime water. If there is an excess of the hydrate, the mixture is known as milk of lime, or white-wash. Calcium oxide combines with carbon dioxide to form calcium monocarbonate, which occurs in nature as calcite, marble or limestone. This substance by itself is only slightly soluble in pure water, but with the addition of another molecule of carbon dioxide and one molecule of water, it forms calcium bicarbonate, which is highly soluble, and is the form in which calcium is taken up from calcium carbonate rocks by rain water, which contains carbon dioxide in solution.

The bicarbonate is precipitated from water by taking away from it the extra molecule of carbon dioxide, which may be done either by heating the water sufficiently hot and sufficiently long, or by treating it with calcium or sodium hydrate, and in other ways which will absorb the carbon dioxide molecule. The solubility of the resulting calcium monocarbonate in pure water is about two grains per gallon, although it is less in hot water containing sodium or potassium carbonate.

Magnesium Carbonate.—The magnesium carbonates are similar in their properties to the corresponding calcium salts, with the exception that the monocarbonate of magnesium is quite soluble, so that in order to secure the precipitation of the magnesia it is necessary to convert it to the hydrate, which is relatively insoluble.

The carbonate salts of lime and magnesia are commonly referred to as "temporary hardness," because they are precipitated to a considerable degree by merely heating the water, which drives off carbon dioxide from the bicarbonate, forming the monocarbonate, which, in the case of lime at least, is relatively insoluble.

Calcium Sulphate.—Sulphate of lime, or calcium sulphate, occurs in nature with the addition of seven molecules of water as gypsum, or alabaster, which when heated dry, gives up some of the water of crystallization and becomes a fine, white powder known as plaster of Paris. Calcium sulphate is soluble in water, to the extent of 138.4 grains per gallon at 60 degs. F., and even at 300 degs. F., is still soluble to the extent of 30 to 40 grains per gallon. When concentration occurs in the boiler, the calcium sulphate crystallizes out as a



SCALE LOOSENED FROM PLATES OF BOILERS; ALSO BOILER TUBE NEARLY FILLED WITH SCALE

hard, porcelain-like scale, which is both very resistant to the passage of heat and difficult of removal, differing in this respect from the carbonate, which forms a soft porous scale in the boiler.

Methods of removing calcium sulphate from water supplies depend upon replacing the sulphate radical by a carbonate or other radical, forming an insoluble calcium salt. The most common treatment is by means of soda ash, that is, sodium carbonate, the result of the reaction being calcium carbonate, which is insoluble, and sodium sulphate, which is very soluble and also harmless in the boiler at any ordinary concentration.

Magnesium Sulphate.—Magnesium sulphate is highly soluble, but when calcium salts are also present in the boiler, it reacts with them, forming calcium sulphate, which is deposited as hard scale. Magnesium sulphate is removed by replacement of the sulphate radical with a hydrate radical, as by calcium hydrate. The calcium sulphate thus formed is removed by treating it with soda ash.

Chlorides.—Both calcium and magnesium chlorides are found in boiler feed water, the magnesium chloride being particularly undesirable, as it breaks down, when heated to boiler temperature, probably forming magnesia and hydrochloric acid, thus producing corrosion. Calcium and magnesium chlorides are converted to insoluble salts by the same reagents ordinarily employed to treat sulphates.

Silica, Alumina and Iron.—Except in a few sections, these impurities are not troublesome.

Sodium and Potassium Salts.—In some water supplies, particularly near the sea, sodium chloride (common salt) occurs in large quantities. There is no practical way to remove it, except by distillation. In other localities, sodium carbonate, or more usually bicarbonate, is found. The latter, known also as the acid carbonate, can be converted to the monocarbonate by reaction with hydrate of lime, and if there are not sufficient sulphates and chlorides of calcium and magnesium to absorb the monocarbonate, suitable reagents, such as sulphate of lime, can be added. The chief difficulties caused by the sodium salts are priming and foaming, due to their concentration in the boiler, the remedy for which is more frequent blowing down.

Acids.—Mineral acids are found in some water supplies, particularly sulphurous and sulphuric acids in water from coal mines. Organic acids may be present in water from swamps or in water containing sewage. As all of the acids are rendered harmless by the reagents used for the treatment of carbonates and sulphates of calcium and magnesium, they present no difficulties.

Air and Carbon Dioxide Gas.—The part played by dissolved air in the corrosion of boilers and hot water piping has come to be understood only in recent years. *W. H. Walker*, of the Massachusetts Institute of Technology, says: "Engineering magazines continue to publish lengthy articles upon the pitting of boiler tubes, the rusting of water supply systems, the red water plague, anti-corrosion compounds, and the like. These papers describe the symptoms, and generally prescribe a cure, but say never a word as to the cause of the trouble. . . He (the engineer) continues to drug his boiler or physic his hot water supply system, in a vain attempt to cure the disease, but takes no steps to prevent it. Corrosion is an electrolytic phenomenon, and can be understood by electrical engineers on purely electrochemical grounds. It takes place at ordinary temperatures only in the presence of water, through the reaction $Fe + 2H^{+} \longrightarrow Fe^{++} + 2H$. This means that a metallic iron atom, electrically neutral, impacts with two hydrogen ions present in the water, and which carry electrical charges. The result is the production of an iron ion which takes up the electrical charges from the two hydrogen ions, and the deposition of two atoms of hydrogen. . . The retarding action of the hydrogen film, which is stable in the absence of oxygen and any acid-forming compounds, is so controlling that from this point of view oxygen (or air) may be said to be the cause of corrosion. If oxygen be completely removed from the boiler feed water, the boilers will not pit nor corrode. If oxygen be separated from the feed of ordinary hot water supply lines, the red water plague and other corrosion troubles will disappear. . . The greater the concentration of hydrogen ions, the more rapid will be corrosive action, hence if any substance forming hydrogen, such as carbonic acid or bicarbonates, or sulphur dioxide, or any acid-forming compound, be present, corrosion is accelerated. On the other hand, if an alkaline material, such as soda ash, or caustic soda, be present, the number of hydrogen ions is decreased, and corrosion is retarded. If enough hydroxyl (the active ion of an alkaline compound) be present, practically all of the hydrogen will disappear and corrosion will entirely cease."

F. H. Speller says: "The degree of æration of the water is the controlling factor in hot water supply lines, so that it is of the first importance, where iron pipe is used, to provide for the removal of as much as possible of the free oxygen and carbonic acid."

The ordinary chemical treatment of water for the removal of carbonates and sulphates of calcium and magnesium also disposes of the carbon dioxide dissolved in the water. Air is most readily removed by heating and spraying the water, the solubility of air in water being zero at the boiling point. The relative volumes of oxygen which water when exposed to the atmosphere will hold in solution at different temperatures are as follows:

Degs. C.	Degs. F.		Degs. C.	Degs. F.	
0	32	.01019	30	86	.00524
5	41	.00891	40	104	.00448
10	50	.00787	50	122	.00385
15	59	.00704	60	140	.00325
20	68	.00635	80	176	.00197
25	77	.00575	100	212	.00000

MODERN METHODS OF SOFTENING WATER

Except for certain special methods for producing small quantities of softened cold water, there have been no changes in the chemical methods employed, for more than fifty years. Hydrate of lime, in the form of lime water or milk of lime, still remains the most economical and practicable means for neutralizing acids, absorbing carbon dioxide and converting bicarbonates to carbonates or hydrates. Likewise soda ash is the preferred means for transforming sulphates, chlorides and nitrates to carbonates. Where the respective amounts of carbonates and sulphates are in the right proportion, a single chemical, sodium hydrate, can be employed both for absorbing carbon dioxide and for transforming sulphates and chlorides.

Other methods for producing non-scale-forming water are distillation, the expense of which is ordinarily prohibitive, and the use of so-called zeolites. Zeolites are suitable only for correcting permanent hardness. When used in connection with water containing temporary hardness, they introduce into the treated water sodium carbonate in quantities proportional to the amount of lime and magnesium carbonates removed. For this reason they are not suitable for softening water for boiler feed purposes.

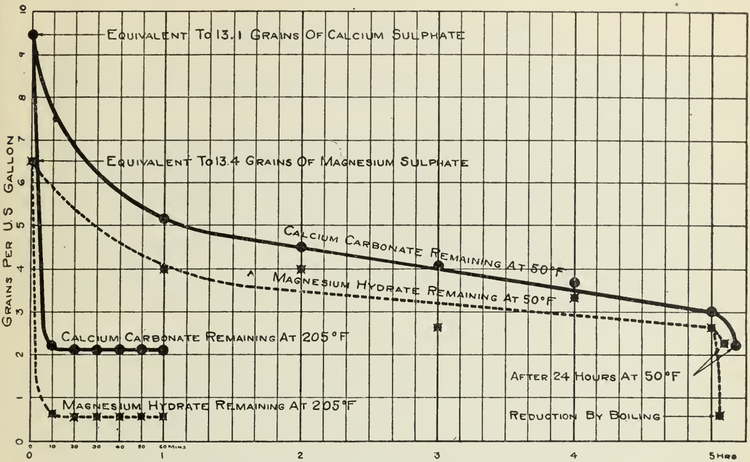
While the chemical reagents used for softening water are limited chiefly by the availability and cheapness of certain substances, the engineering methods and appliances by means of which the softening process is carried out have undergone a radical evolution, so that their efficiency has been increased several fold. These improvements have to do principally with the proper use of heat for accelerating the chemical reaction and the perfection of means by which the chemical reagents are fed more accurately and the labor of handling chemicals and removing precipitates from the apparatus is greatly lessened.

The Effects of Heat Upon Chemical Reactions.—Chemical reactions are enormously accelerated by heat. The statement has been made that the rate of reaction doubles for each 10 degs. C. added to the temperature. Another estimate is that chemical reactions are speeded up approximately as the twentieth power of the absolute temperature. These two formulas are not in agreement, but the fact remains that there is a tremendous increase in speed of reactions with rise in temperature. In the softening of water by means of lime and soda ash, the reactions involved are greatly accelerated by heat, so that better results can be obtained at a temperature of 200° to 210° F. in a few minutes than in cold water in several hours.

Experimental results, which are supported by experience with Hot Process Softeners in practical service, demonstrate that ten minutes at the boiling temperature will soften water to a lower degree of hardness than can be secured by the same number of *hours* at 50° F., the same softening reagents being used in each case. Analyses of the treated water also show that the incrusting substances in the water which has been softened at 200° to 210° F. are much less in amount than those remaining in solution in water softened at 50° F.

Not only is the chemical reaction completed much sooner in hot water than in cold water, but the resulting precipitates are of such a nature that they can be more quickly removed by sedimentation.

The effect of temperature on rate and degree of precipitation is graphically illustrated in the curves on page 223.



VALUE OF HEAT IN WATER SOFTENING

The same quantities of the same treating solution were added to equal amounts of the water at 205° F. and at 50° F. Solid curves show calcium carbonate remaining in solution after treating calcium sulphate with sodium carbonate (soda ash). Dotted curves show magnesium hydrate remaining in solution after treating magnesium sulphate with calcium hydrate (lime). In all tests the theoretical quantity of softening chemicals was used to combine with the scale forming solids. In 10 min. the hot sample had a little less calcium carbonate than the cold sample had after 24 hr. In 10 min in the hot sample all the possible precipitation of magnesium hydrate had taken place. After 24 hr. the cold sample had three times as much magnesium hydrate left in solution as the hot sample after 10 min. The same minimum was reached by boiling the cold sample.

Cost of Treating Water.—The following are the amounts of reagents required for treating 1000 gallons of water containing one grain per gallon of the different scale-forming substances. It can be seen that the cost is very small:

1 gr. per gal. of calcium sulphate requires .111 lb. of soda ash per 1000 gal. to convert it to calcium carbonate.

1 gr. per gal. of calcium bicarbonate (reported as the carbonate) requires .117 lb. of 90% hydrated lime per 1000 gal. to convert it to calcium carbonate.

1 gr. per gal. of calcium chloride requires .137 lb. of soda ash per 1000 gal. to convert it to calcium carbonate.

1 gr. per gal. of magnesium sulphate requires .14 lb. of soda ash and .098 lb. of hydrated lime per 1000 gal. to convert it to magnesium hydrate.

1 gr. per gal. of magnesium bicarbonate (reported as the monocarbonate) requires .28 lb. of hydrated lime per 1000 gal. to convert it to magnesium hydrate.

1 gr. per gal. of magnesium chloride requires .18 lb. of soda ash and .123 lb. of hydrated lime per 1000 gal. to convert it to magnesium hydrate.

1 gr. per gal. of free carbon dioxide requires .24 lb. of hydrated lime per 1000 gal. for its absorption.

The modern scientific treatment for softening boiler feed water is described in the *Harrison Safety Boiler Works Engineering Bulletin No. 20.*

FEED WATER HEATING

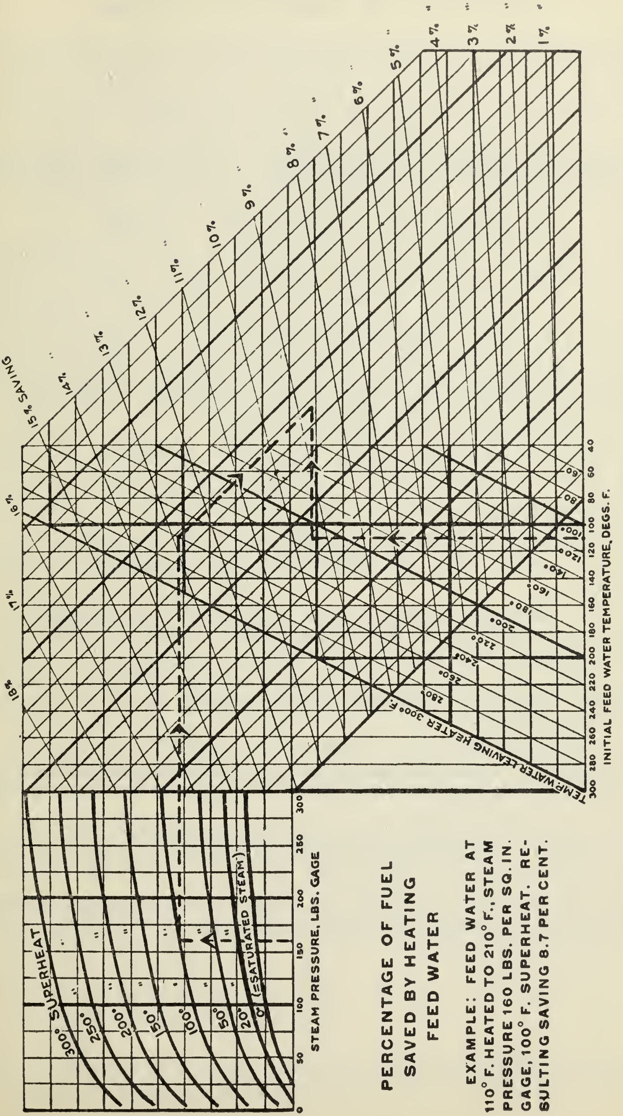
Heating boiler feed water by means of exhaust steam effects a saving of about 1% of fuel for each 11° F. rise in the temperature of the feed water. See the chart on page 225.

Besides the fuel saving, heating the feed water increases the actual steaming capacity of the boilers. The part of the heat required to turn the water into steam supplied before the water enters the boiler diminishes the work of the heating surfaces, or if, on the other hand, the transmission of heat remains the same as before, more steam will be generated from the same heating surface, and from the same amount of fuel and hot gases, where the feed water is preheated. The increase in capacity is in nearly the same proportion as the fuel saving. About one-seventh of the fuel is saved by heating the water from 50° to 210° F., and the steaming capacity is increased by one-sixth.

The saving from an open heater is greater than from a closed heater, since the heat in the condensate from the exhaust steam is wasted by a closed heater, while the open heater saves it. The closed heater also wastes the condensed steam itself, because in the absence of an oil separator it is not suitable as boiler feed, while the open heater makes use of this distilled water as boiler feed. To make 7 lb. of hot boiler feed the closed heater requires 7 lb. of cold water and 1⅙ lb. of exhaust steam, whereas the open heater requires only 6 lb. of cold water and 1 lb. of exhaust steam, assuming that the water is heated from 50° to 210° F. in both cases. This is an important consideration, especially in condensing plants, where the supply of exhaust steam from auxiliaries may be limited. As a matter of fact, however, while open heaters, in which the steam comes into actual immediate contact with the water, will raise the temperature of the water to within 1° or 2° of the exhaust steam temperature, closed heaters with ⅓ sq. ft. per HP., the maximum amount of heating surface ordinarily installed, will not come nearer than to within 15° to 30° of the steam temperature, even when the surface is clean and the heater free from air binding. Accumulations of scale on one side of the surface and grease on the other cut down the heat transmission, while unless the heater has a large surplus of exhaust steam passing through it, air accumulates, blanketing and rendering inactive a part of the surface. The closed heater also does not provide for the elimination of the air and other gases driven off from the water by heat, as does the open heater. Recent researches have shown that the air in solution is the principal cause of corrosion in boilers and piping.

An open heater can be used as a catch-all for all available supplies of exhaust steam and hot water, such as drips and condensate, suitable for boiler feeding. If the amount of exhaust steam from auxiliaries is not sufficient to raise the feed water to the desired temperature, steam can advantageously be bled from an intermediate stage of the main turbine, such steam working with much higher efficiency than that which goes through to the condenser. If, on the other hand, there is not sufficient boiler feed water at certain times, as during periods of light load, to absorb all of the auxiliary exhaust, the surplus not required for feed heating can automatically be passed by a flow valve to an intermediate stage of the main turbine and utilized therein. Further discussion of this matter will be found on page 254.

The subject of feed water heating is fully treated in "Cochrane Heaters for Steam Power Plants," published by the *Harrison Safety Boiler Works*.



PERCENTAGE OF FUEL SAVED BY HEATING FEED WATER

EXAMPLE: FEED WATER AT 110° F. HEATED TO 210° F., STEAM PRESSURE 160 LBS. PER SQ. IN. GAGE, 100° F. SUPERHEAT. RESULTING SAVING 8.7 PER CENT.

HEATING BY EXHAUST STEAM

Great economies are realized where the surplus of exhaust steam above that required for heating the boiler feed water can be applied to heating buildings or drying materials. A good oil separator should be installed to purify the steam of oil so that the returns, or condensate, can be brought back to the heater and used over again as boiler feed. The open heater then serves as a receiver or return tank for the condensate, at the same time automatically admitting the amount of raw water required to make up the total boiler feed supply. The oil separator can be attached to and form a part of the heater.

One pound of steam used first in an engine or turbine and then in a heating system will replace about 1½ pounds of steam required where the engine or turbine is run condensing and live steam is used in the heating system. If it is necessary to decide between running non-condensing the year around, using exhaust steam for heating, and running condensing the year around, using live steam for heating, the relative sizes of the heating and power loads and the length of the heating season should be considered.

Obviously in many cases, and especially where the power load is large in comparison with the heating load, the best arrangement will be a combined system. We may note several classes of plants:

1. Where all of the exhaust of the engine or turbine can be utilized for heating during the heating season, it will pay to shut down the condenser.

If only part of the exhaust is needed for heating, say less than one-half, the following courses are open:

2. If there are two or more engines or turbines, one or more can be run condensing, and the others can exhaust into the heating system during the heating season.

3. An engine and turbine or two turbines can be arranged in series, part of the exhaust from the first being applied to heating and the remainder expanded through the second to the condenser.

4. If compound engines are installed, as they should be for running condensing, steam can be withdrawn for heating from the intermediate receiver of the engine.

5. A bleeder or extraction turbine can be installed, that is, steam can be withdrawn from an intermediate stage of a condensing turbine for use, together with the exhaust from auxiliaries, in the feed water heater and in the heating and drying system.

This subject is discussed exhaustively and commercial systems of exhaust steam heating are described in the "Exhaust Steam Heating Encyclopedia," published by the *Harrison Safety Boiler Works*.

The first and most important use for the exhaust steam is to heat the feed water, since all of the heat of the exhaust steam so utilized is returned undiminished to the boilers.

Section IV—Boiler Efficiency and Boiler Testing

HEAT BALANCE

One of the first requisites in improving boiler room practice is a record of performance. A feed water meter* should be installed to measure the water evaporated, and the coal consumption determined by some method, as described on page 59. From these quantities the evaporation per pound of fuel can be calculated. If possible, a heat balance should be computed. Where complete data are not available, a calculation based on certain assumptions will often indicate unusual losses.

The *American Society of Mechanical Engineers Boiler Test Code* specifies the following items for the heat balance. The separate items can be based on the coal as fired, dry coal or combustible:

1. The heat absorbed by the boiler.

2. Loss due to the evaporation of moisture in the coal.

3. Loss due to the heat carried away by the steam formed by the burning of the hydrogen of the coal.

4. The loss due to heat carried away in the dry flue gases.

5. Loss due to burning to carbon monoxide instead of dioxide.

6. Loss due to combustible in the ash and the refuse. This might also include the combustible carried into the settings and stack by the draft.

7. Loss due to heating the moisture in the air.

8. Loss due to unconsumed hydrogen and hydrocarbon, radiation, and unaccounted for.

Each of the items is computed as a number of BTU. per lb. of dry coal or per lb. of combustible, according to the basis selected, and is then computed as a % of the heating value per lb. The following discussion of the items is on the basis of dry coal.

1. **The Heat Absorbed by the Boiler.**—This is calculated from a Steam Table (see pages 229-231) and is equal to

---

* The Cochrane V-Notch Meters and Metering Heaters are described in the companion volume to this publication "Finding and Stopping Waste in Modern Boiler Plants," sent upon request by the *Harrison Safety Boiler Works.*

$$\frac{W\,(H - h_f + sS)}{F}$$

where W = lb. water evaporated in test period,
H = total heat of saturated steam above 32° F., BTU per lb.,
= $h + L$ from table,
h_f = feed water temperature above 32° F.,
s = specific heat of superheated steam,
$= .43 + 1{,}476{,}000\,\frac{p}{T^3}$ (p = lb. per sq. in. gauge, T = abs. temp. F.),
S = degrees of superheat, if any,
F = lb. of dry coal consumed.

The heat absorbed per lb. of dry coal is also equal to 970.4 times the equivalent evaporation per lb. of dry coal.

To find the % absorbed, divide by the heat value of one lb. of dry coal.

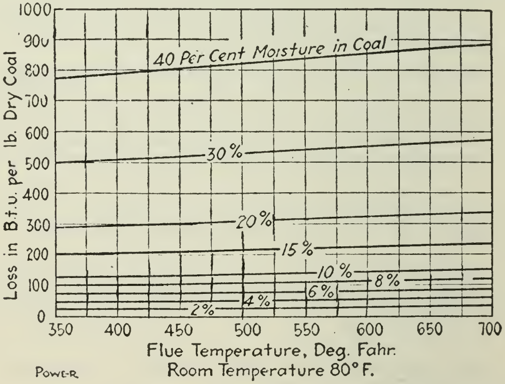
2. **Moisture in the Coal.**—Water in coal must be evaporated and superheated to the flue temperature at atmospheric pressure. Heat is thus rejected to the chimney, and hence moisture in coal, in addition to being a dead weight, is an active heat waster.

This loss can be determined from the following formula:

Loss in BTU. per lb. of dry coal
$= W\,[212 - t + 970.4 + .47\;\;(T - 212)]$
W = the fraction of dry coal which is moisture,
t = temperature of the coal as fired,
T = temperature of the flue gases.

.47 is the mean specific heat of superheated steam.

For illustration, assume a coal of 14,000 BTU. (dry basis), 4% moisture, 80° F. room temperature and 500° F. stack temperature. The heat loss would be 49.5 BTU.



Power

LOSS DUE TO MOISTURE IN COAL

The above chart, due to *H. O'Neill*, shows the loss due to moisture. The % loss is usually insignificant, being for the case given .35%.

PROPERTIES OF SATURATED STEAM

From Steam Tables of Marks & Davis, copyrighted. Reproduced by permission of the authors and of the publishers, Longmans, Green & Co.

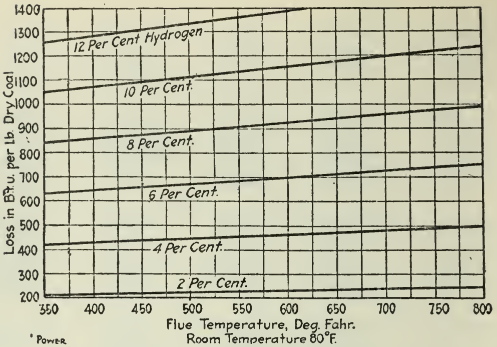
Temp. Fahr. (t)	Vacuum (Referred to a 30 in. barometer)	Sp. Vol. cu. ft. per lb. (v or s)	Sensible Heat of the liquid above 32° F. (h or q)	Latent heat of evap. (L or r)	Entropy	
					Water (n or e)	Evap. $\left(\frac{L}{T} \text{ —or— } \frac{r}{T}\right)$
32°	29.8196	3294.	0.00	1073.4	0.0000	2.1832
35°	29.7966	2938.	3.02	1071.7	0.0062	2.1666
40°	29.7523	2438.	8.05	1068.9	0.0162	2.1394
45°	29.6998	2033.	13.07	1066.1	0.0262	2.1127
50°	29.6375	1702.	18.08	1063.3	0.0361	2.0865
55°	29.5643	1430.	23.08	1060.6	0.0459	2.0609
60°	29.478	1208.	28.08	1057.8	0.0555	2.0358
65°	29.378	1024.	33.07	1055.0	0.0650	2.0110
70°	29.261	871.	38.06	1052.3	0.0745	1.9868
75°	29.127	743.	43.05	1049.5	0.0840	1.9631
80°	28.971	636.8	48.03	1046.7	0.0932	1.9398
85°	28.791	545.9	53.02	1044.0	0.1023	1.9169
90°	28.583	469.3	58.00	1041.2	0.1114	1.8944
95°	28.345	405.0	62.99	1038.4	0.1205	1.8723
100°	28.074	350.8	67.97	1035.6	0.1295	1.8505
105°	27.764	304.7	72.95	1032.8	0.1383	1.8292
110°	27.411	265.5	77.94	1030.0	0.1471	1.8082
115°	27.013	231.9	82.92	1027.2	0.1559	1.7876
120°	26.562	203.1	87.91	1024.4	0.1645	1.7674
125°	26.052	178.4	92.90	1021.6	0.1730	1.7475
130°	25.48	157.1	97.89	1018.8	0.1816	1.7279
135°	24.84	138.7	102.88	1016.0	0.1900	1.7086
140°	24.12	122.8	107.87	1013.1	0.1984	1.6896
145°	23.33	109.0	112.86	1010.3	0.2067	1.6709
150°	22.43	96.9	117.86	1007.4	0.2149	1.6525
155°	21.45	86.4	122.86	1004.5	0.2231	1.6344
160°	20.35	77.2	127.86	1001.6	0.2311	1.6165
165°	19.14	69.1	132.86	998.7	0.2391	1.5989
170°	17.80	62.0	137.87	995.8	0.2470	1.5816
175°	16.33	55.7	142.87	992.9	0.2550	1.5645
180°	14.71	50.15	147.88	989.9	0.2628	1.5476
185°	12.93	45.25	152.89	986.9	0.2706	1.5310
190°	10.98	40.91	157.91	983.9	0.2783	1.5146
195°	8.85	37.04	162.92	980.9	0.2860	1.4984
200°	6.53	33.60	167.94	977.8	0.2937	1.4824
205°	4.00	30.53	172.96	974.7	0.3012	1.4666
210°	1.24	27.80	177.99	971.6	0.3087	1.4510
212°	0.08	26.79	180.00	970.4	0.3118	1.4447

Temp. Fahr. (t)	Pressure lb. per sq. in. gauge	Sp. Vol. cu. ft. per lb. (v or s)	Heat of the liquid (h or q)	Latent heat of evap. (L or r)	Entropy	
					Water (n or e)	Evap. $\left(\frac{L}{T} \text{ or } \frac{r}{T}\right)$
212°	00.00	26.79	180.00	970.4	0.3118	1.4447
215°	00.90	25.35	183.0	968.4	0.3163	1.4354
220°	2.49	23.15	188.1	965.2	0.3238	1.4199
225°	4.21	21.17	193.1	962.0	0.3312	1.4052
230°	6.07	19.39	198.2	958.7	0.3384	1.3905
235°	8.09	17.78	203.2	955.4	0.3458	1.3754
240°	10.27	16.32	208.3	952.1	0.3531	1.3607
245°	12.61	15.01	213.4	948.7	0.3603	1.3465
250°	15.12	13.82	218.5	945.3	0.3675	1.3321
255°	17.83	12.74	223.5	941.9	0.3747	1.3179
260°	20.72	11.76	228.6	938.4	0.3818	1.3040
265°	23.82	10.87	233.7	934.9	0.3888	1.2903
270°	27.15	10.06	238.8	931.4	0.3959	1.2766
275°	30.70	9.32	243.9	927.9	0.4029	1.2629
280°	34.48	8.64	249.0	924.3	0.4098	1.2496
285°	38.54	8.02	254.2	920.5	0.4168	1.2363
290°	42.85	7.46	259.3	916.9	0.4235	1.2232
295°	47.43	6.94	264.4	913.2	0.4304	1.2101
300°	52.30	6.46	269.6	909.5	0.4371	1.1972
305°	57.47	6.03	274.7	905.7	0.4439	1.1844
310°	62.97	5.62	279.9	901.9	0.4507	1.1717
315°	68.79	5.26	285.0	898.0	0.4573	1.1592
320°	74.93	4.91	290.2	894.2	0.4640	1.1468
325°	81.45	4.60	295.4	890.2	0.4705	1.1346
330°	88.30	4.306	300.6	886.3	0.4771	1.1225
335°	95.6	4.035	305.8	882.3	0.4837	1.1103
340°	103.3	3.787	311.0	878.3	0.4902	1.0984
342°	106.5	3.692	313.0	876.7	0.4928	1.0937
344°	109.7	3.600	315.1	875.1	0.4954	1.0889
346°	113.0	3.511	317.2	873.4	0.4980	1.0841
348°	116.4	3.425	319.3	871.8	0.5006	1.0794
350°	119.9	3.342	321.4	870.1	0.5032	1.0748
352°	123.4	3.261	323.5	868.5	0.5058	1.0700
354°	127.0	3.182	325.6	866.8	0.5084	1.0653
356°	130.7	3.105	327.7	865.2	0.5110	1.0607
358°	134.4	3.030	329.8	863.5	0.5136	1.0560
360°	138.3	2.957	331.9	861.8	0.5162	1.0514
362°	142.2	2.887	334.0	860.2	0.5187	1.0468
364°	146.1	2.820	336.1	858.5	0.5213	1.0422
366°	150.2	2.754	338.2	856.8	0.5238	1.0377

					Entropy	
Temp. Fahr. (t)	Pressure lb. per sq. in. gauge	Sp. Vol. cu. ft. per lb. (v or s)	Heat of the liquid (h or q)	Latent heat of evap. (L or r)	Water (n or e)	Evap. $\left(\frac{L}{T}\text{—or—}\frac{r}{T}\right)$
368°	154.3	2.690	340.3	855.1	0.5263	1.0332
370°	158.6	2.627	342.4	853.4	0.5289	1.0286
372°	162.9	2.567	344.5	851.7	0.5314	1.0240
374°	167.2	2.508	346.6	850.0	0.5340	1.0194
376°	171.7	2.450	348.7	848.3	0.5364	1.0150
378°	176.2	2.394	350.8	846.5	0.5389	1.0105
380°	180.9	2.340	352.9	844.8	0.5413	1.0060
382°	185.6	2.287	355.0	843.1	0.5439	1.0015
384°	190.4	2.236	357.2	841.3	0.5464	0.9971
386°	195.3	2.186	359.3	839.6	0.5488	0.9928
388°	200.4	2.137	361.4	837.8	0.5513	0.9884
390°	205.5	2.089	363.5	836.1	0.5539	0.9840
392°	210.7	2.043	365.6	834.3	0.5565	0.9796
394°	216.0	1.999	367.7	832.5	0.5590	0.9752
396°	221.4	1.955	369.9	830.7	0.5615	0.9708
398°	226.8	1.913	372.0	829.0	0.5639	0.9665
400°	232.4	1.872	374.1	827.2	0.5663	0.9623
410°	261.6	1.679	384.7	818.2	0.5786	0.9409
420°	293.7	1.510	395.4	809.0	0.5908	0.9198
430°	328.3	1.361	406.2	799.6	0.6029	0.8990
440°	366.1	1.229	417	790.1	0.6149	0.8785
450°	406	1.11	428	780	0.627	0.858
460°	450	1.00	439	770	0.639	0.837
470°	498	0.90	451	759	0.651	0.816
480°	550	0.81	462	748	0.662	0.796
490°	607	0.73	473	737	0.674	0.776
500°	669	0.66	484	725	0.686	0.755

The moisture loss with small percentages of moisture increases about 1% for every 10% of free moisture. The moisture in high-grade coals will average about 4%, and it does not usually pay to spend much effort to reduce it.

3. **Hydrogen in the Coal.**—A pound of hydrogen burned in an inclosed calorimeter in which the resulting water vapor is condensed will produce 62,000 BTU. Therefore, other things being equal, the richer the coal is in hydrogen, the higher its heat value. In a bomb calorimeter, the latent heat of evaporation of the water which results from the burning of the hydrogen with oxygen is credited to the coal, but in an open furnace, this heat, together with that required for superheating from boiling temperature at atmospheric pressure to the flue temperature, is wasted. Therefore, to estimate the true available heat of the coal, a deduction, depending upon the percentage of hydrogen, should be made from the calorimeter value.



Power

LOSS DUE TO HYDROGEN IN COAL

The above chart, by *H. O'Neill*, shows the loss due to hydrogen. It is possible for several coals to show the same value in the calorimeter and yet differ as much as 3 to 4% in actual commercial value as steam producers.

The hydrogen loss may be computed from the following formula:

Loss in BTU. per lb. of dry coal

$$= 9\ Hy\ [212 - t + 970.4 + .47\ (T - 212)]$$

where Hy = the fraction by weight of dry coal which is hydrogen,
t = temperature degrees F. of coal as fired,
T = flue gas temperature degrees F.

Where an ultimate analysis of the coal is not available, this item goes into the unaccounted for losses.

4. **Heat in Dry Chimney Gases.**—The loss of heat in the chimney gases is directly proportional to the amount of air admitted to the boiler setting, and to the temperature of the gases. Even in well-cared-for settings, the inleakage amounts to 25% of the gases passing through the up-take. It is usually the largest loss, and the one in which the greatest saving can be made. It can be brought down to 15%. A large loss indicates dirty boilers, leaky baffles, defective setting or improper handling of fire or draft, the cause being easily determined by physical inspection.

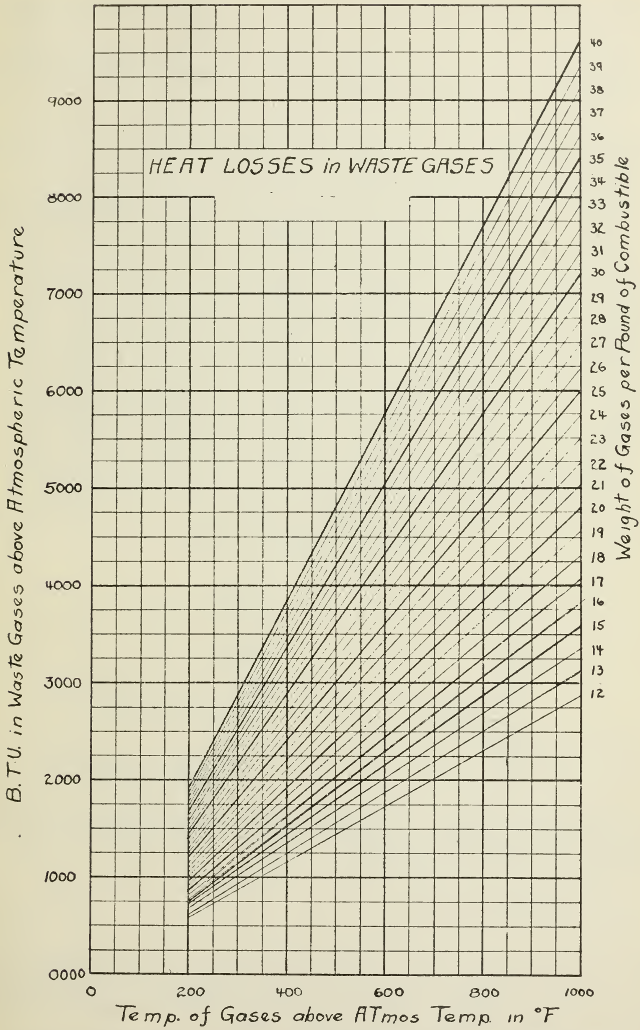
The loss of heat in BTU. in the flue gases per lb. of dry coal equals $.24W\ (T - t)$.

W = weight of flue gases in lb. per lb. of dry coal,
T = temperature of flue gases,
t = temperature of atmosphere in boiler room,
.24 is the mean specific heat of the flue gases.

The weight of flue gases per lb. of dry coal is computed from the formulas on page 104 or page 162.

The chart on page 233 shows the loss corresponding to different temperatures and different weights of gases. Use chart on page 164 for obtaining weight of gases from the % CO_2. The chart gives weight of air; add one to get weight of gases per pound of combustible.

The specific heat of a substance is the number of BTU. required to raise the temperature of one lb. of the substance one deg. Fahr. To be most



LOSS IN CHIMNEY GASES AT DIFFERENT TEMPERATURES exact the temperature range should be given. The mean specific heat is the average of the specific heat for each degree between the range desired, and can be taken as .24 for flue gases at constant pressure.

The specific heat of a mixture of gases is obtained by multiplying the specific heat of each constituent gas by the fraction by weight of that gas in the mixture and adding the products.

DENSITY OF GASES AT 32° F. AND 29.92 IN. OF MERCURY.—*Steam*, adapted from Smithsonian Tables.

Gas	Chemical Symbol	Specific Gravity Air=1	Weight of One Cubic Foot Pounds	Volume of One Pound Cubic Feet	Relative Density, Hydrogen=1	
					Exact	Approximate
Oxygen	O	1.053	.08922	11.208	15.87	16
Nitrogen	N	0.9673	.07829	12.773	13.92	14
Hydrogen	H	0.0696	.005621	177.90	1.00	1
Carbon Dioxide	CO_2	1.5291	.12269	8.151	21.83	22
Carbon Monoxide	CO	0.9672	.07807	12.809	13.89	14
Methane	CH_4	0.5576	.04470	22.371	7.95	8
Ethane	C_2H_6	1.075	.08379	11.935	14.91	15
Acetylene	C_2H_2	0.920	.07254	13.785	12.91	13
Sulphur Dioxide	SO_2	2.2639	.17862	5.598	31.96	32
Air	. . .	1.0000	.08071	12.390	. . .	. . .

MEAN SPECIFIC HEATS AT CONSTANT PRESSURE FOR TEMPERATURES USUALLY ENCOUNTERED

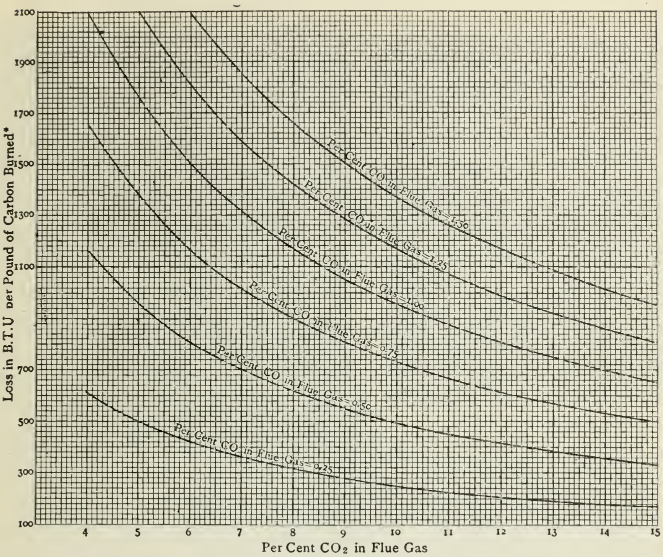
O_2	.217	
N_2	.247	
H_2	3.42	
Air	.24	
CO	.243	
CO_2	.21	
Flue gases	.24	average (*Gebhardt*)
H_2O vapor	.48	
H_2O	1	
Fe	.168	(32° to 2000° F.)
Cu	.09	(32° to 212° F.)

5. **Carbon Monoxide.**—The loss due to burning the carbon to CO instead of CO_2 may assume large proportions, but is ordinarily almost nothing. Loss in BTU. per lb. of dry coal equals

$$C\ (10{,}150)\ \frac{CO}{CO_2 + CO}$$

where CO and CO_2 are the respective fractions by volume in the flue gas, and C is the lb. of carbon per lb. of dry coal, from the ultimate analysis. The chart on page 235 gives the heat loss for different percentages of CO in combination with different percentages of CO_2.

6. **Combustible in the Ash.**—It is assumed that all combustible in the ash is carbon, although there may be a slight amount of volatile. If the ash is analyzed, the loss can be figured as follows:



LOSS DUE TO UNCONSUMED CARBON CONTAINED IN THE CO IN THE FLUE GASES

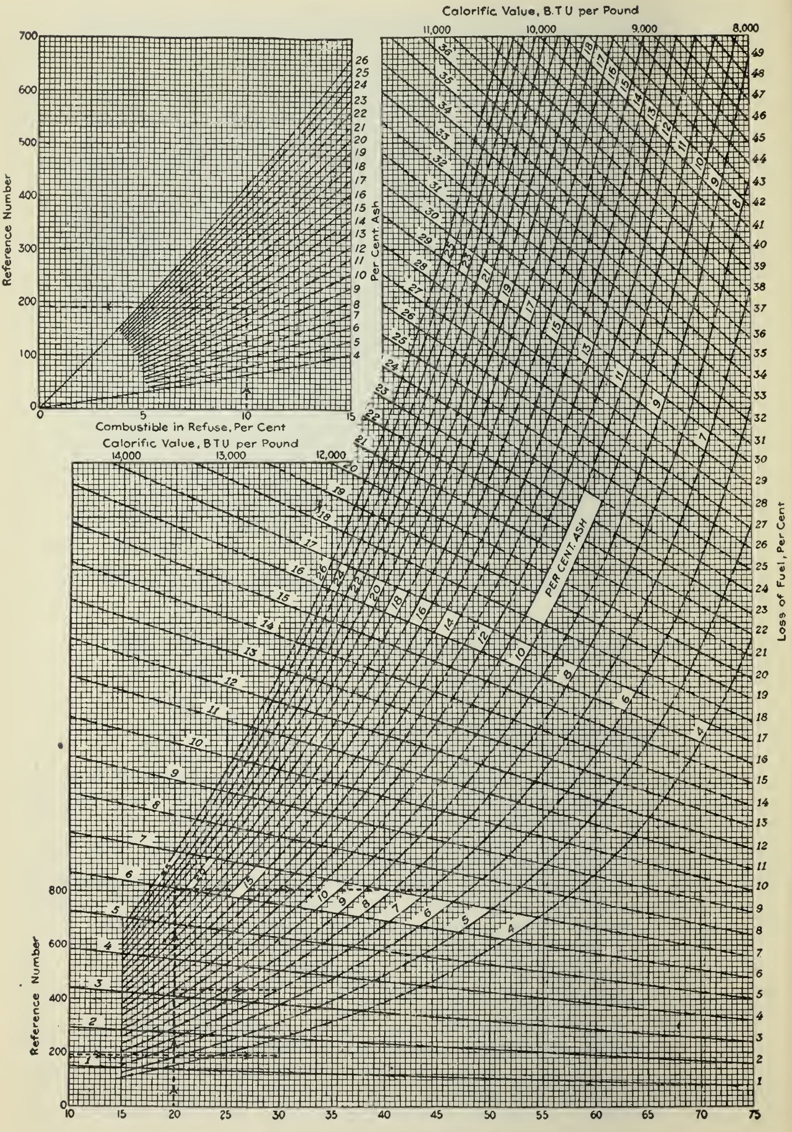
Loss from combustible in ash, in BTU. per lb. of dry coal

$$= \frac{C}{1 - C} \times A \times 14600$$

where C = fraction of carbon in refuse,
A = fraction of ash in dry coal by analysis.

A comparison of the weights of coal fired and refuse removed from the ash-pit does not show the % of ash in the coal. If the coal has been analyzed, a comparison of the % of ash by analysis and the % of refuse will show the combustible loss through the grate. The heat lost thereby per lb. of fuel is computed by assuming all of the combustible in the ash to be of the same heat value, *i. e.*, all carbon. A more rational method, which checks more closely with the above, is to analyze the refuse. The combustible is given as a % of the refuse. The proximate analysis must be known to find the % of the fuel going into the ash-pit. The % of combustible in the refuse is a meaningless figure unless it is taken in connection with % of ash in the coal. The curve on page 236, by *C. W. Hubbard,* can be used to determine the % of fuel lost.

Under the best conditions, the loss due to combustible will be as small as 1%. In extreme conditions it may run up to 20%. An average of 77 tests at the St. Louis plant of the *Geological Survey* showed 4.9%. It ranged from 1.68 to 18.88%, and covered almost every variety of coal under fair operating conditions. *Hays* says that the average boiler furnace deposits 5% of its combustible in the refuse.



LOSS FROM COMBUSTIBLE IN REFUSE

(See explanation opposite)

C. C. Linde states that the loss in unburned fuel may be reduced to 10 or 15% of the ash, and therefore to about 2% of the fuel as fired.

H. D. Fisher says: "Except where the grate is too coarse and entirely unsuited for the fuel, or the coal clinkers badly, the refuse should not contain over 30% combustible." This item in the heat balance should not exceed 3%.

Hays suggests a douche of water to show up coal and coke in the ash. "Give the fireman an object lesson at the ash pile when it rains. You must expect to find some coke in the ash. In the absence of a laboratory analysis to determine the combustible in the ash, weigh all of the coal and ash each day. Take a couple of shovelfuls of each barrow of ash, douche with water and carefully pick over. Weigh the coal and ash proper."

The loss of combustible in the ash is due to:

1. Character of coal.
2. Condition of equipment.
3. Methods employed in handling fires:
    - (*a*) Carelessness in cleaning fire.
    - (*b*) Carelessness in shoveling fuel.
    - (*c*) Too much shaking of grates.
    - (*d*) Too much working of fire.

The improper use of the fire-room tools is responsible for much of the carbon in the ash. Rakes and slice-bars are usually too heavy, so that effective work is impossible.

The loss due to sensible heat in red-hot ashes is almost negligible, being less than ½% with coal having less than 15% ash.

7. Moisture in the Air.—There is a loss of heat due to the necessity of superheating the moisture in the air from atmospheric temperature to the temperature of the flue gases. The amount of moisture in the weight of air used, or the volume of air used, can be computed from the table below, if the relative humidity is known. The percentage or relative humidity can be obtained from the weather reports, or by means of a psychrometer.

Absolute humidity is the amount of moisture, often expressed in grains, in a cubic foot of space. Relative humidity is the ratio of the absolute humidity to the absolute humidity if the water vapor were saturated at the given temperature. The temperature of saturation, also called the dew-point, is that given in the ordinary steam table. The psychrometer is the instrument used for determining humidity. The sling type, which is much more satisfactory than the stationary, consists of two thermometers suitably mounted, the bulb of one being covered by a close-fitting piece of muslin, which is well moistened in pure water, hence the term "wet bulb." They are whirled at about 200 rev. per min. Psychrometric tables can readily be obtained, which will give the dew-point, the relative humidity, and the absolute humidity corresponding to given dry and wet bulb readings from the psychrometer.

Use of Chart on page 236.—For 12515 BTU. coal analyzing 12% ash, with 20% combustible in refuse, start at the bottom at the figure 20, indicating the % of combustible in the refuse, and run vertically up to the curved line marked 12 representing the % of ash in the coal. Then run horizontally to the right to the vertical line representing 12515 BTU. per lb. The loss is therefore 3.5%, read from the slightly-inclined lines.

The chart in the upper left-hand corner is used for low percentages. With 10% combustible in the refuse; coal with a heat value of 12515 BTU. and containing 12% ash, start at the line 10 and run vertically to the curve 12 and then horizontally to the left. Read the reference number 190 and then using the same reference number on the larger chart run horizontally to the vertical line 12515 BTU. This point is midway between lines 1 and 2, and represents 1.5% loss of coal through the grates.

Weight of Water Vapor in Saturated Atmosphere

R. C. Carpenter.

Temp. degrees F.	Weight of mixture, lb. per cu. ft. Air	Vapor	Total	Weight of vapor per lb. of air
0	.0863	.000079	.086379	.00092
12	.0840	.000130	.084130	.00155
22	.0821	.000202	.082302	.00245
32	.0802	.000304	.080504	.00379
42	.0784	.000440	.078840	.00561
52	.0766	.000627	.077227	.00819
62	.0747	.000881	.075581	.01179
72	.0727	.001221	.073921	.01680
82	.0706	.001667	.072267	.02361
92	.0684	.002250	.070717	.03289
102	.0659	.002997	.068897	.04547
112	.0631	.003946	.067042	.06253
122	.0599	.005142	.065046	.08584
132	.0564	.006639	.063039	.11771

8. **Unaccounted-for Heat.**—All of the above 7 items are added together, and subtracted from the total heat value of 1 lb. of dry coal, or 1 lb. of combustible, according to the basis on which the heat balance is being computed, and the difference is termed the heat loss unaccounted for. This includes loss due to unconsumed hydrogen and hydrocarbons passing out in the flue gases, and to radiation from the boiler and setting. It also includes the errors of observation, which are by no means small, particularly in sampling flue gases and determining their temperature.

H. D. Fisher states that in a series of tests where the conditions were such that there was a marked evolution of hydrogen and hydrocarbon gases, and where the flue gases were carefully analyzed for these constituents, the loss due to them about equalled that due to unburned CO.

Absolute radiation losses are uncertain, but *Fisher* suggests the following averages for total unaccounted-for losses:

12 to 15% for small boilers at low rates,
7 to 8% for fair-sized units at average loads,
2 to 3% for very large boilers at high rates.

W. M. Selvey, referring to English practice, says that the radiation loss is no more than 3% in a boiler evaporating 20,000 lb. of water per hr., when the boiler is well lagged. The figure may be taken to be 2% for a 30,000 lb. per hr. boiler, and for larger sizes. Excessive radiation is always easy to locate, and not difficult to remedy.

EFFICIENCIES

The general definition of the efficiency of an apparatus is the ratio of the energy made use of by the apparatus to the energy available for its use.

The efficiencies of the different parts of a boiler installation and of the installation as a whole are defined in so many different ways that there is some confusion. The following definitions are used:

What is ordinarily called the efficiency of the boiler, is in reality the efficiency of the boiler, furnace and grate, and is the heat absorbed per lb. of fuel divided by the heating value. The value obtained will be the same whether the efficiency is based on dry fuel or on fuel as fired. All of the fuel cannot be burned, as some goes through the grates, and it is obviously unfair to charge this to the boiler. On the other hand, the boiler user must pay for it and is justified in charging it against the boiler and furnace.

This over-all efficiency can be expressed as

$$E = \frac{w\,(H - h_f)}{W\,H'}$$

w = lb. of water evaporated in unit of time,
W = lb. of coal fired in unit of time,
H = heat in 1 lb. of steam as delivered from boiler,
h_f = heat in 1 lb. of water as received by boiler,
H' = heat value of 1 lb. of coal.

Efficiency based upon combustible burned, as defined in the *A. S. M. E. Power Test Code*, may be called the efficiency of furnace and boiler combined. It furnishes an approximate means of comparing the results of different tests, when the losses of unburned coal due to grates, cleaning, etc., are eliminated.

The combustible burned is determined by subtracting from the weight of coal supplied to the boiler the moisture in the coal, the weight of ash and unburned coal withdrawn from the furnace and ash-pit, and refuse, if any, withdrawn from the tubes, flues and combustion chamber, including ash carried away in the gases, if any. The combustible used for determining the calorific value is the weight of coal less the moisture and ash found by analysis.

"True boiler efficiency" is defined by the *Bureau of Mines* as the ratio of heat absorbed by the boiler to the heat available for the boiler. A boiler cannot absorb heat from a source below the temperature of the boiler contents, but the ordinary over-all boiler efficiency charges the boiler with such heat. The more air used in the furnace the greater is the % of total heat below the boiler steam temperature.

Hays suggests that furnace efficiency should be considered apart from boiler efficiency. Gas analysis is the one and only means of furnace testing. For purposes of study consider everything from the grate to the damper except the naked boiler as a part of the furnace. Increase in furnace and grate efficiency without change of their design is primarily a question of air supply, generally a reduction of air supply.

Tests on the Torpedo Boat "Biddle" by the *Bureau of Mines* showed that the quantity of heat absorbed increases nearly at the same rate as the quantity of available heat. In other words, the true boiler efficiency is nearly constant. For most boilers, if combustion is fairly complete, over-all efficiency as well as true boiler efficiency will remain nearly constant with almost any rate of combustion.

COMPARISONS OF BOILERS BY THEIR EFFICIENCIES

For comparing the steaming qualities of two boilers, a very careful study must be made of the conditions in each boiler. The over-all efficiencies will not show a correct comparison, for the over-all efficiency is affected by the size and character of the coal, the air spaces in the grate, the skill or lack of skill of the fireman in preventing the loss through the grate, the condition of the setting, and the entire method of operation, as well as the actual efficiency of the boiler itself. The "true boiler efficiency" should therefore be used in comparing two boilers.

EFFICIENCY OBTAINABLE WITH DIFFERENT COALS

High volatile coals generally do not give as good results as high fixed-carbon coals. With hand-firing, air is not admitted in sufficient quantities immediately after firing for at least 2 min. after the firing period, during which times most of the volatile is distilled. A little volatile is distilled in the succeeding minutes.

The efficiency drops and the percentage of heat loss unaccounted for increases as the ease of liberation of the volatile increases. The table below shows the results with various coals, tabulated in accordance with the ease of liberation of combustible and heavy hydrocarbon gases at 600° Centigrade.

EFFECT OF VOLATILE CONTENT ON BOILER EFFICIENCY.—*U. S. Bureau of Mines*

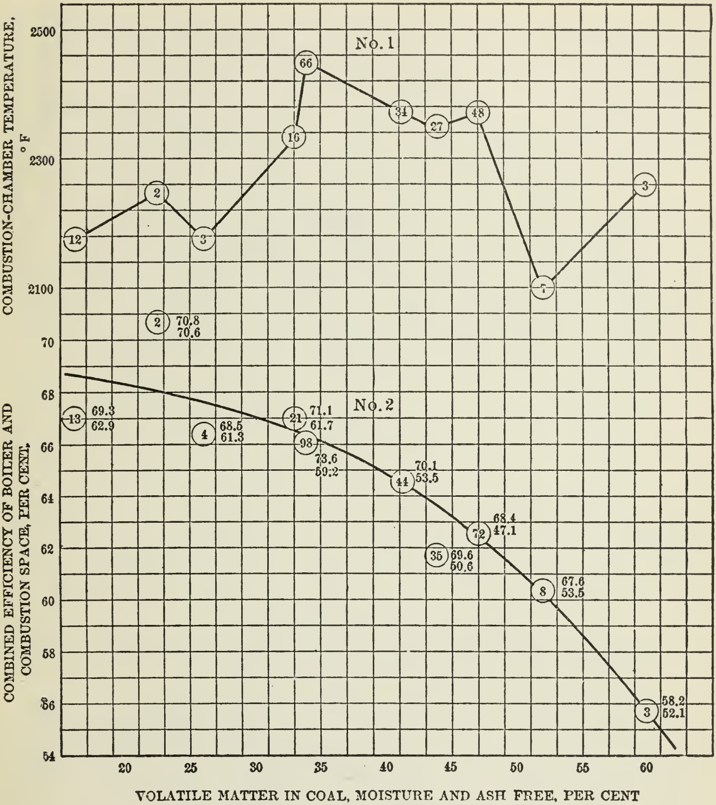
Coal No.	Volatile matter in dry coal (per cent).	Combustible gas at 600°.[a]	Heavy hydrocarbon gases at 600°.[a]	Steam test No.	Boiler efficiency (per cent).	Unaccounted-for loss (per cent).	CO in flue gas (per cent).	Rate of firing.[b]
W. Va. 11	20.8	60	5.6	56	68.3	5.4	0.05	18.1
Pa. 19	32.9	....	....	498 308	63.9 65.6	8.7 7.1	.04 .02	20.4 21.0
Lab. 3	30.4	75	8.5	....	....	....	....	....
Ill. 19	33.0	108	10.5	160–63	63.7	12.5	.19	19.0
W. Va. 13	32.6	116	13.8	179–80	68.1	11.1	.14	15.7
Wyo. 4	45.4	....	....	399	56.4	15.9	.07	24.0
Lab. 18	43.4	142	19.4	....	....	....	....	....
Wyo. 1	43.8	165	15.1	63	54.9	11.2	.25	22.7
Tex. 4	41.6	....	....	291 298	59.9 51.2	6.9 17.6	.0 .0	23.1 35.2

[a] Volume in cubic centimeters from 10 grams in ten minutes, laboratory test.
[b] Pounds of dry coal per square foot of grate surface per hour.

W. Va. 11. Pocahontas-bed, "smokeless" coal.
Pa. 19. Pittsburg bed, Westmoreland County.
Lab. 3. Pittsburg bed, Connellsville, Fayette County, Pa., similar to Pa. 19.
Ill. 19. No. 7 seam, Zeigler, Franklin County.
W. Va. 13. "No. 2 gas coal," Page, Fayette County.
Wyo. 4. Bituminous coal, Hanna, Carbon County.
Lab. 18. Bituminous coal, Diamondville, Uinta County, Wyo., somewhat similar to Wyo. 4.
Wyo. 1. Subbituminous, Sheridan district, 22 per cent moisture.
Tex. 4. Lignite, Wood County, 36 per cent moisture.

The volatile is not entirely responsible for the incomplete combustion. The chemical composition and physical state also account for it.

The figure on page 241, by the *Bureau of Mines*, shows the efficiency obtainable with coals of different volatile content. The efficiency of the boiler and combustion space drops from 68 to 56% when the volatile rises from 20 to 60%. The numbers in the circles give the number of tests averaged. The numbers outside the circles show the maximum and minimum efficiencies obtained. It will be noted that the minimum efficiency at each point drops off very rapidly as the volatile increases, while the highest efficiencies at each point are about the same for all groups, except that in which the volatile is highest. There is no particular difficulty in burning low volatile coal, consequently the efficiencies in all such tests are very good. As the volatile becomes higher, the difficulty in burning the coal increases, and most tests come out with a low efficiency. The conclusion is that a great deal more care and skill are required to burn high volatile than low volatile coals.

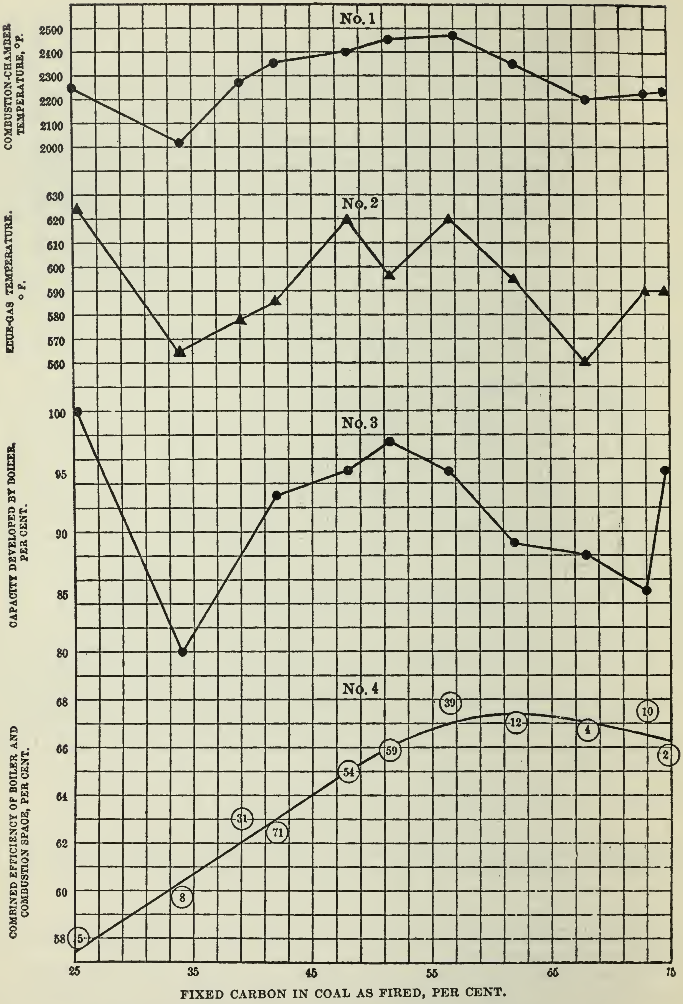


EFFECT OF VOLATILE IN COAL

Effect of the volatile matter in moisture-and ash- free coal on: Combustion-chamber temperature (No. 1); combined efficiency of boiler and combustion space (No. 2).

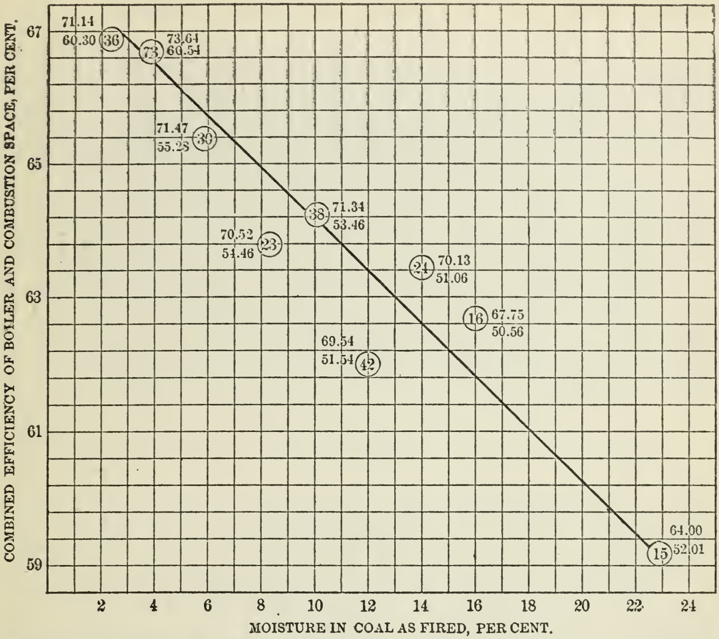
The figure on page 242 shows the efficiency obtainable with coals of different fixed-carbon content.

The figure on page 243, due to the *Bureau of Mines*, shows that the combined efficiency of boiler and combustion space drops from 67% to 59% as the moisture in the fuel increases from 3 to 23%. The curve is plotted regardless of the nature of the fuels. Coals high in moisture are also high in ash; so that the effect is a combination of the moisture and ash effects.



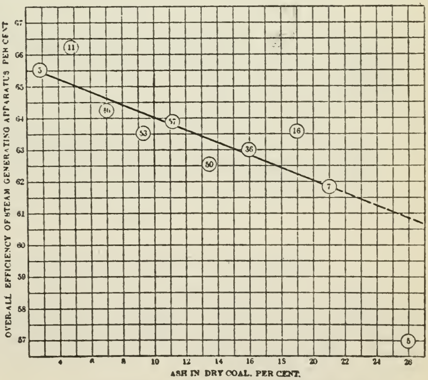
EFFECT OF CARBON ON BOILER PERFORMANCE

Relation between the percentage of fixed carbon in coal and: Combustion-chamber temperature (No. 1); flue-gas temperature (No. 2); capacity developed by boiler (No. 3); combined efficiency of boiler and combustion space (No. 4).

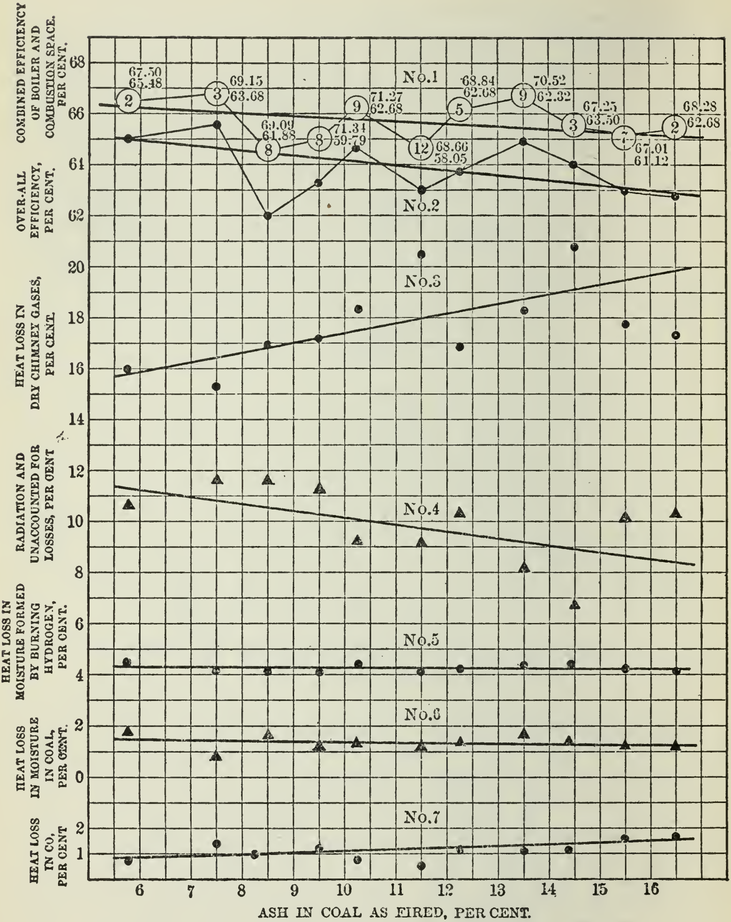


EFFECT OF MOISTURE IN COAL ON THE COMBINED EFFICIENCY OF BOILER AND COMBUSTION SPACE

The figure to the right, by the *Bureau of Mines*, shows that the over-all efficiency drops from 65½ to 61¾% as the percentage of ash in the dry coal increases from 2 to 21%. This includes the grate, therefore the drop in efficiency is more marked than in the figure on page 244. The latter indicates a drop of only 1.5% in combined efficiency of boiler and combustion space when the ash increases from 5 to 17%. High efficiencies can often be obtained with high ash coals, but the chances are much poorer than with low ash coals.



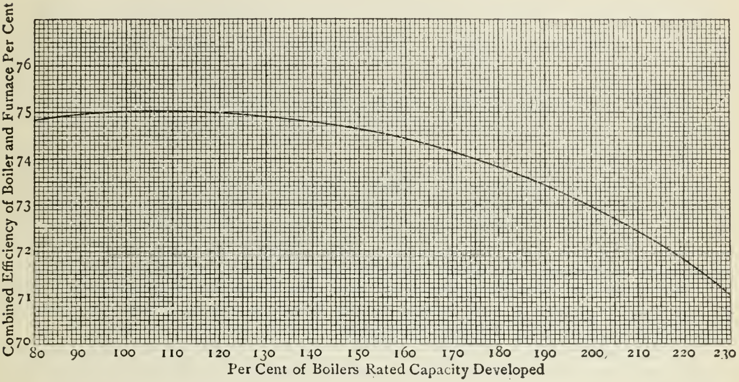
EFFECT OF ASH ON OVER-ALL EFFICIENCY



EFFECT OF ASH ON GENERAL BOILER PERFORMANCE

Relation of the percentage of ash in coal to: Combined efficiency of boiler and combustion space (No. 1); over-all efficiency of steam-generating apparatus (No. 2); heat loss in dry chimney gases (No. 3); radiation and unaccounted-for losses (No. 4); heat loss in moisture formed by burning hydrogen (No. 5); heat loss in moisture in coal (No. 6); heat loss in CO (No. 7). The ordinates of curves 1, 3, 4, 5, 6 and 7 are expressed as % of the heat of "combustible" ascending from the grate and therefore should add approximately to 100. Tests made with Illinois coals only.

RELATIONS OF BOILER CAPACITY TO EFFICIENCY



APPROXIMATE VARIATION OF EFFICIENCY WITH CAPACITY UNDER TEST CONDITIONS

The above curve, from *Steam*, shows the relation of capacity to efficiency for B. & W. boilers. The maximum "true" boiler efficiency occurs at that load at which the sum of the constant loss due to radiation plus the flue-gas loss bears a minimum ratio to the total heat supplied to the boiler. If the percentage of flue-gas loss is constant or decreasing, this point of maximum efficiency will occur at infinite load. If it is increasing, maximum true boiler efficiency will occur at a point where its rate of increase is equal to the total losses divided by the heat supplied. As maximum "true" boiler efficiency is always found at a comparatively light load, it is evident that the percentage of flue-gas losses actually increases with increasing load.

In the actual boiler plant, furnace efficiency will, up to a certain point, increase with an increase in capacity. This is ordinarily at a greater rate than is the decrease in true boiler efficiency beyond the maximum just mentioned, therefore to a certain point, usually somewhat above the rated capacity, the combined boiler and furnace efficiency will increase with an increase in capacity. The load at which maximum over-all efficiency occurs may be increased by using a larger combustion space and by providing for the absorption of more heat by radiation. See page 194.

BOILER TRIALS

Summary of Boiler Test Code.—The following summary covers the boiler test section of the report of the *Power Test Committee of the American Society of Mechanical Engineers.* If more detail is required, consult the complete Power Test Code, which may be obtained from the Secretary, 29 West 39th Street, New York City.

Object and Preparations.—Determine the objects of the test, take the dimensions, note the physical conditions, examine for leakage, and install the testing appliances.

Fuel.—Determine the character of the fuel to be used. For tests to compare a boiler with another boiler, a coal regarded commercially as a standard for the locality should be used. In the Eastern States, Pocahontas and New River semi-bituminous, No. 1 Buckwheat Anthracite containing not over 13% ash, and Youghiogheny and Pittsburgh Bituminous coals are considered standard. In some sections east of the Alleghenies, semi-bituminous Clearfield and Cumberland coals are also considered standards. There are no special grades of coal mined in the Western States which are generally considered standard for testing purposes.

A coal selected for maximum efficiency and capacity tests should be the best of its class and especially free from slagging and unusual clinker-forming impurities.

Apparatus and Instruments.—The apparatus and instruments required for boiler tests are:

(*a*) Platform scales for weighing coal and ashes.
(*b*) Graduated scale attached to the water glass.
(*c*) Tanks and platform scales for weighing the water or suitable water meters.
(*d*) Pressure gauges, thermometers and draft gauges.
(*e*) Calorimeters for determining the calorific value of the fuel and the quality of the steam.
(*f*) Pyrometers.
(*g*) Gas analyzing apparatus.

Operating Conditions.—Determine what the operating conditions and method of firing should be to conform to the object in view, and see that they prevail throughout the trial as nearly as possible.

Where uniformity in the rate of evaporation is required, arrangements can usually be made to dispose of the steam so that this can be obtained. In a single boiler it may be accomplished by discharging the steam through the waste pipe, and regulating the amount by means of a valve. In a battery of boilers in which only one is tested, the draft may be regulated on the remaining boilers to meet the varying demands for steam, leaving the test boiler to work under a steady rate of evaporation.

Duration.—The duration of a test to determine the efficiency of a hand-fired boiler should be at least 10 consecutive hours. In case the rate of combustion is less than 25 lb. per sq. ft. of grate per hr., the test should be continued for such a time as may be required to burn a total of 250 lb. of coal per sq. ft. of grate. With a boiler using a mechanical stoker, the duration should be at least 24 hr. If the stoker is of the type which permits the quantity and condition of the fuel bed at the beginning of the test to be estimated accurately, the duration may be reduced to 10 hr., or such time as may be required to burn the above-noted 250 lb. per sq. ft.

Starting and Stopping.—The conditions relating to the temperature of the furnace and the boiler, the quantity and quality of live coal and of ash on the grates, the water level and the steam pressure should be as nearly as possible the same at the end as at the beginning of the test.

The furnace being well heated by a preliminary run, burn the fire low and clean it thoroughly, leaving enough live coal spread evenly over the grate, say from 2 to 4 in., to serve as a foundation for a new fire. Note quickly the thickness of the fuel bed, as nearly as it can be estimated from measurements, also the water level, the steam pressure and the time, which should be recorded as the starting time. Fresh coal should then be fired from that weighed for the test, the ash-pit thoroughly cleaned, and the regular work of the test proceeded with.

Before the end of the test, the fire should be burned low and cleaned in such a manner as to leave the same amount of live coal on the grate as at the start. When this condition has been reached, observe quickly the water level, the steam pressure and the time, which is recorded as the stopping of the test. If the water level is lower than at the beginning, a correction should be made by computation, rather than by feeding an additional amount of water.

In a plant containing several boilers, the fires should be cleaned one after the other as rapidly as may be, and each one after cleaning charged with enough fuel to maintain a thin fire in good working condition. After the last fire is cleaned and in working condition, burn all the fires low, say to 4 to 6 in. Note quickly the thickness of each, also the water levels and time, which is recorded as a starting time. When the time arrives for closing the test, the fires should be quickly cleaned one by one and when this work is completed, they should be burned low, the same as at the start, and the various final observations noted. In the case of a large boiler having several furnace doors, the above directions pertaining to starting and stopping in a plant of several boilers may be followed.

Where a boiler is provided with a mechanical stoker other than a chain grate, so regulate the coal as to burn the fire to the low condition required for cleaning. Shut off the coal feeding mechanism, and fill the hoppers level full. Clean the ash or dump plate, note quickly the depth and condition of the coal on the grates, the water level, the steam pressure and the time, which is recorded as the starting time. Then start the coal feeding mechanism, clean the ash-pit and proceed with the regular work of the test.

When the time arrives for the close of the test, shut off the coal-feeding mechanism, clean the hoppers, and burn the fire to the same low point as at the beginning. When this condition is reached, note the water level, steam pressure and time, which is recorded as the stopping time.

In the case of chain grate stokers, the desired operating conditions should be maintained for a half hour before starting the test, and for a like period before its close, the height of the stoker gate or the throat plate and the speed of the grate being the same during both of these periods.

Records.—The records of results should be complete. Half-hourly readings on the instruments are usually sufficient. If there are sudden fluctuations, the readings should be taken every 15 min.

In hand-fired plants, the coal should be weighed and delivered to the fireman in portions sufficient for one hour's run, thereby ascertaining the degree of uniformity of firing. Likewise in stoker tests, the weight of coal fed each hour to the furnace should be obtained.

Records should be such as to ascertain the consumption of feed water per hr., thereby determining the uniformity of evaporation.

Quality of Steam.—If the boiler does not produce superheated steam, its quality should be determined by the use of a calorimeter. If the steam is superheated, its temperature should be taken at 15 min. intervals.

Sampling and Drying Coal.—During the progress of the test, the coal should be regularly sampled for the purpose of analysis, in accordance with the usual method.

Ashes and Refuse.—The ashes and refuse withdrawn from the furnace and ash-pit during the progress of the test and at its close should be weighed as far as possible in a dry state. If wet, the amount of moisture should be determined and allowed for. The sample taken for this purpose can also be used for determining the unburned carbon and for the fusing test.

Analysis of Coal.—The coal should be analyzed and its calorific value determined.

Analysis of Flue Gases.—For approximate determination, the Orsat apparatus, or some modification thereof, should be employed. If momentary samples are obtained, analyses should be made as frequently as possible, say every 15 or 30 min., depending on the skill of the operator, noting the furnace and firing conditions at the time the sample is taken. If the sample as drawn is a continuous one, the intervals may be longer.

Smoke Determination.—In tests of bituminous coals, observations should be made regularly throughout the test, at intervals of 5 min., noting at the same time the furnace and firing conditions.

Data and Results.—All data should be recorded. A complete form is given in the code, and includes 55 items with subdivisions. The principal items are given in the following table. Unless otherwise indicated, the items should be the averages of the data.

PRINCIPAL DATA AND RESULTS OF BOILER TESTS

(1) Grate surface (width———, length———)....................sq. ft.
(2) Total heating surface....................................sq. ft.
(3) Date..
(4) Duration..hr.
(5) Kind and size of coal...................................
(6) Steam pressure by gauge.........................lb. per sq. in.
(7) Temperature of feed water entering boiler...............deg. F.
(8) Percentage of moisture in steam or number of degrees of superheating...................................% or deg.
(9) Percentage of moisture in coal.............................%
(10) Dry coal per hr...lb.
(11) Dry coal per sq. ft. of grate surface per hr..............lb.
(12) Equivalent evaporation per hr. from and at 212° F.........lb.
(13) Equivalent evaporation per hr. from and at 212° F. per sq. ft. of heating surface..lb.
(14) Rated capacity per hr. from and at 212° F.................lb.
(15) Percentage of rated capacity developed.....................%
(16) Equivalent evaporation from and at 212° F. per lb. of dry coal......lb.
(17) Equivalent evaporation from and at 212° F. per lb. of combustible..lb.
(18) Calorific value of 1 lb. of dry coal by calorimeter.......BTU.
(19) Calorific value of 1 lb. of combustible by calorimeter....BTU.
(20) Efficiency of boiler, furnace and grate....................%
(21) Efficiency based on combustible............................%

Charts.—In trials having for an object the determination and exposition of the complete boiler performance, the entire log of readings and data should be plotted on a chart and represented graphically.

VALUE OF BOILER TESTS

The evaporative test has its uses, but it does not serve to fix the individual causes of fuel losses. To yield reliable and valuable information it requires team work by a number of experienced and disinterested men. The temptation to take advantage of many little things is almost too much for ordinary human nature. So many things can be done under the nose of an inexperienced engineer that all such tests should be taken with a wide margin of allowance for errors, both unintentional and otherwise.

Hays mentions a trick of having a boiler and furnace extra hot at the start of a test. This gives a high false water level. At the end of the test, the fire is allowed to simmer down, using the stored heat-energy in the water, so that the true water level will drop, which requires a large quantity of water to be pumped in to bring the level to the original mark. The amount may come to 10% of the total water evaporated.

It is well to break the blow-off line, so that any leakage from the boiler can be detected.

CONVERSION FACTORS

Water at 60° F. weighs 58,361 grains per U. S. gal.
8.337 lb. per U. S. gal.
62.3677 lb. per cu. ft.
1 atmosphere (standard) = 760. millimeters of mercury.
29.921 2 in. of mercury.
33.900 6 ft. of water.
14.696 9 lb. per sq. in.
1.033 29 kilograms per sq. centimeter.
1 centimeter = 0.393 700 in.
1 square centimeter = 0.155 000 sq. in.
1 U. S. gallon = 231. cu. in.
0.133 681 cu ft.
3.785 43 liters or cu. decimeters.
3785.43 cu. centimeters.
32. gills.
8. pints.
4. quarts.
0.832 702 4 Imperial gal.
1 grain = 1/7000 lb. (av.)
0.002 285 71 ounce (av.).
0.064 798 9 gram.
1 barrel water = 31 to 31½ gallons.

DENSITY, SPECIFIC VOLUME AND SPECIFIC HEAT OF WATER AT DIFFERENT TEMPERATURES

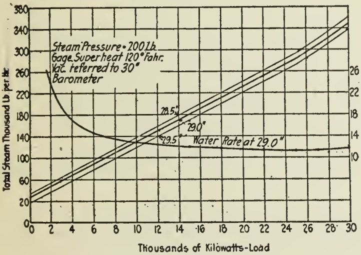
(From Marks and Davis's Steam Tables)

Temp., deg. fahr.	Pressure, lb. per sq. in.	Specific volume, cu. ft. per lb.	Density, lb. per cu. ft.	Specific heat	Temp., deg. fahr.	Pressure, lb. per sq. in.	Specific volume, cu. ft. per lb.	Density, lb. per cu. ft.	Specific heat
20	0.06	0.01603	62.37	1.0168	240	24.97	0.01692	59.11	1.012
30	0.08	0.01602	62.42	1.0098	250	29.82	0.01700	58.83	1.015
40	0.12	0.01602	62.43	1.0045	260	35.42	0.01708	58.55	1.018
50	0.18	0.01602	62.42	1.0012	270	41.85	0.01716	58.26	1.021
60	0.26	0.01603	62.37	0.9990	280	49.18	0.01725	57.96	1.023
70	0.36	0.01605	62.30	0.9977	290	57.55	0.01735	57.65	1.026
80	0.51	0.01607	62.22	0.9970	300	67.00	0.01744	57.33	1.029
90	0.70	0.01610	62.11	0.9967	310	77.67	0.01754	57.00	1.032
100	0.95	0.01613	62.00	0.9967	320	89.63	0.01765	56.66	1.035
110	1.27	0.01616	61.86	0.9970	330	103.0	0.01776	56.30	1.038
120	1.69	0.01620	61.71	0.9974	340	118.0	0.01788	55.94	1.041
130	2.22	0.01625	61.55	0.9979	350	135.0	0.01800	55.57	1.045
140	2.89	0.01629	61.38	0.9986	360	153.0	0.01812	55.18	1.048
150	3.71	0.01634	61.20	0.9994	370	173.0	0.01825	54.78	1.052
160	4.74	0.01639	61.00	1.0002	380	196.0	0.01839	54.36	1.056
170	5.99	0.01645	60.80	1.0010	390	220.0	0.01854	53.94	1.060
180	7.51	0.01651	60.58	1.0019	400	247.0	0.0187	53.5	1.064
190	9.34	0.01657	60.36	1.0029	410	276.0	0.0189	53.0	1.068
200	11.52	0.01663	60.12	1.0039	420	308.0	0.0190	52.6	1.072
210	14.13	0.01670	59.88	1.0050	430	343.0	0.0192	52.2	1.077
220	17.19	0.01677	59.63	1.007	440	381.0	0.0194	51.7	1.082
230	20.77	0.01684	59.37	1.009					

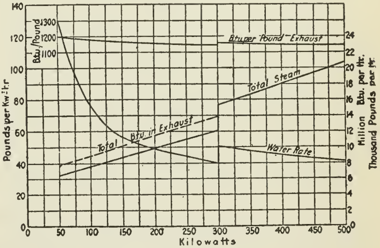
Section V—Boiler Plant Proportioning and Management

BOILER PLANT PROPORTIONING

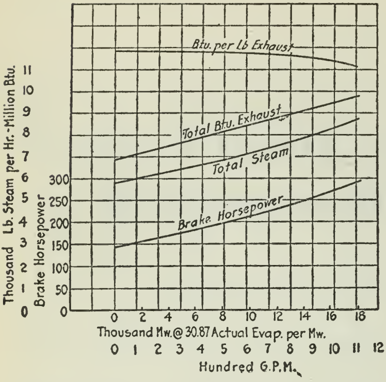
The economy of the boiler plant as a whole depends upon the co-ordination of the several parts. *R. J. S. Piggott* describes the following method of handling this problem, as used in studying the 90,000 Kw. addition to the 74th Street Station of the Interboro Rapid Transit Co., New York, where the entire output is electrical energy from three 30,000 Kw. turbine-driven units. The Willans lines for three different vacuums and the water-rate curve for the main units, as guaranteed by the builder, are shown in Fig. A. The Willans line is a graph showing the relation between steam consumption and output. For engines and turbines it is nearly a straight line, showing that steam consumption is made up of two parts, a constant for all loads and a part varying directly with the load. Similarly in Fig. B are shown the steam consumption and the BTU. in the exhaust, for a 300-Kw. turbine-driven, geared exciter set. Two exciters are so designed that in the event of the failure of one, the other could carry the entire load for a convenient length of time. Fig. C shows the steam consumption and the BTU. in the exhaust of a 1000-gal. per min. turbine-driven boiler feed pump, on the basis of myriawatts of water capacity supplied (the myriawatt is equivalent to 34150 BTU. per hr., or to 1.02 boiler HP.). Fig. D similarly shows the steam consumption of forced draft fans and stokers for various amounts of air supplied to the fire; one unit serving a battery of two boilers consists of two fans driven by a single turbine. Curves in Fig. E show the relation between boiler output and cu. ft. of air required per min., draft pressure and brake



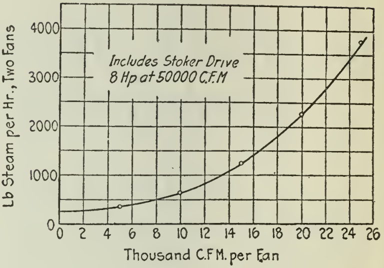
A. WILLANS LINES AND WATER RATE, 30,000 Kw. WESTINGHOUSE TURBINE UNIT



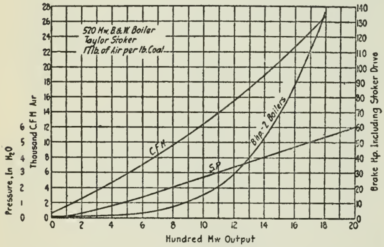
B. INPUT-OUTPUT LINE AND ECONOMY, 300 Kw. EXCITERS



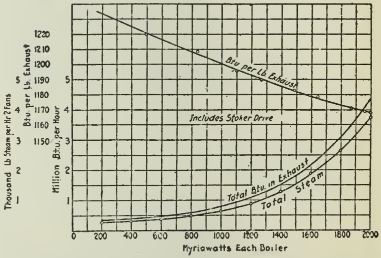
C. INPUT-OUTPUT LINES AND BRAKE HORSEPOWER, BOILER FEED PUMPS



D. STEAM CONSUMPTION AND AIR DELIVERED, FORCED DRAFT BLOWERS

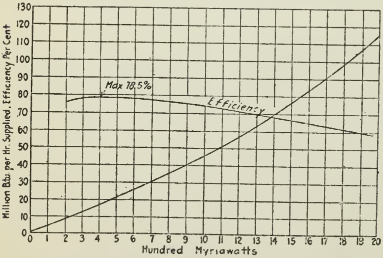


E. AIR, BLAST PRESSURE AND BRAKE HORSEPOWER, FORCED DRAFT FAN



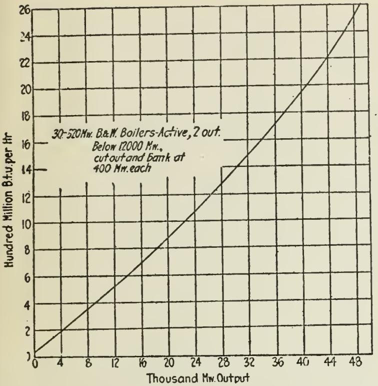
F. STEAM CONSUMPTION AND BOILER OUTPUT, FORCED DRAFT BLOWERS

HP., the latter being useful in considering electric drive for the fan and stoker. Fig. F is constructed from D and E, and shows the steam consumption and the heat in the exhaust of the forced draft blowers at various boiler outputs.

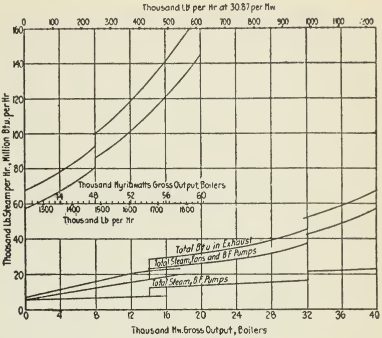


G. BOILER INPUT-OUTPUT AND EFFICIENCY, FROM TESTS

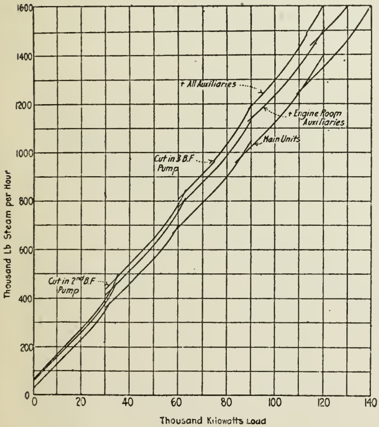
With a fixed number of boilers already installed and paid for, the output efficiency curve G, in connection with the performance of auxiliaries, is about all that is required in determining the best combination for handling different loads. Curve H shows the relation between boiler input in BTU. and output in myriawatts, while Fig. I shows the steam required by auxiliaries, and the heat available in the auxiliary exhaust for various boiler gross outputs. Knowing the steam required by the main units, as shown in Fig. J, the



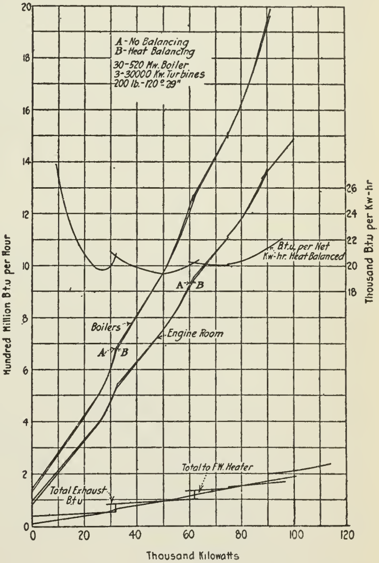
H. BOILER ROOM INPUT-OUTPUT LINE



I. AUXILIARY INPUT-OUTPUT LINES



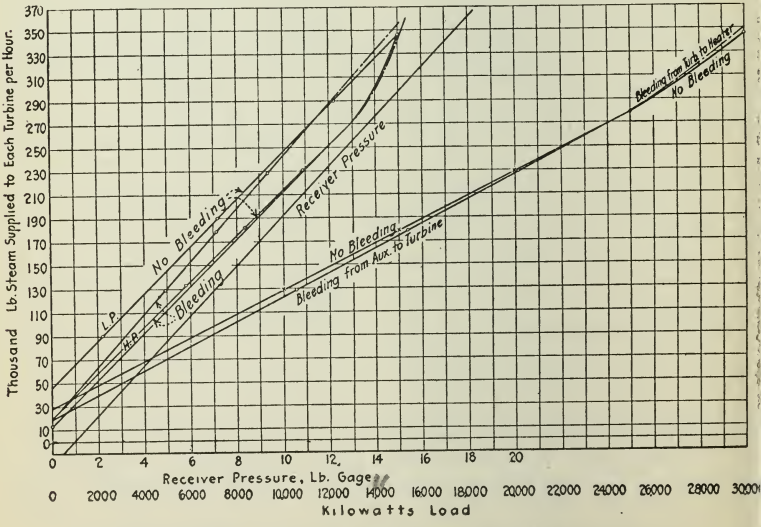
J. ENGINE ROOM STEAM DEMAND



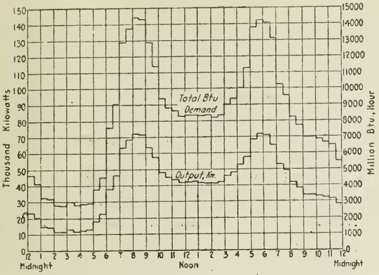
K. PLANT INPUT-OUTPUT LINES

total steam consumption, including engine room and boiler room auxiliaries, is obtained by adding the steam consumption of auxiliaries, as already given. It will be noticed that the most desirable point for cutting in a new unit is a little beyond the most efficient load of the unit already in operation. From I and J the total heat demand is obtained in Fig. K, in which the curves at the bottom show the heat units required in the feed-water heater, and the heat units available from the auxiliary exhaust per kilowatt of output.

Feed Heating and Heat Balancing.—As more auxiliary exhaust is available during lighter loads than is required for feed heating, while not sufficient is available at heavier loads, improved economy can be obtained by bleeding steam from the main units when more heat is required for feed-water heating, and returning steam to the main units from the auxiliary exhaust when there is more heat available from auxiliaries than is required in the feed-water heater, as at periods of light load. This is readily done, since the receiver pressure between the high and low pressure sections of the turbine is less than atmospheric pressure at periods of light load, when the amount of exhaust steam from the auxiliaries is excessive, and is higher than atmospheric pressure at high loads when the amount of auxiliary steam is insufficient. The best adjustment is secured when the amount of auxiliary steam is just enough to heat the feed water at the load at which the receiver pressure between the high and low pressure parts of the main turbine is equal to the auxiliary exhaust pressure. This can be had by using more or less economical drives for the auxiliaries. The effect of bleeding steam to and from the main units upon the efficiency of the latter is shown in Fig. L. For example, from the curve at the bottom of Fig. K, at 60,000 Kw. load, the third unit having been cut in, the heat available for the low-pressure turbine due to the excess auxiliary exhaust is 20,600,000 BTU. per hr., increasing the low-pressure turbine output by 882 Kw., while the resulting increase in receiver pressure decreases the energy available from the high-pressure part of the turbine by 272 Kw., resulting in a net gain of 610 Kw. At 90,000 Kw., with three units, the heat required to be bled to the feed-water system from the low-pressure turbine is 6,400,000 BTU., reducing the output of the low-pressure end by 279 Kw. The drop in receiver pressure increases the output of the high-pressure turbine by 75 Kw., giving a net loss in output

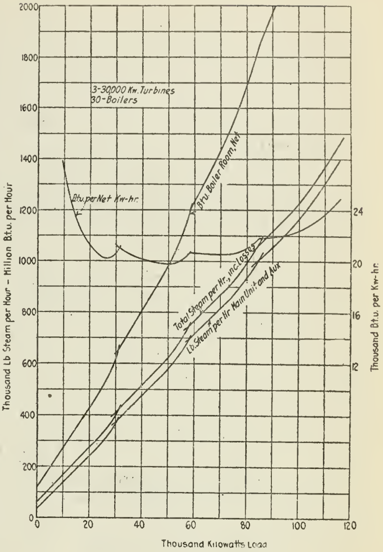


L. CORRECTED WILLANS LINES FOR HEAT BALANCING



M. ANTICIPATED LOAD CURVE AND HEAT INPUT BALANCED

of 204 Kw. By using the load curve of Fig. M and Figs. H and K, the daily BTU. consumption for the two conditions is obtained. From Fig. K it is found that without heat balancing, 19,823,300,000 BTU. are required per day, while with heat balancing only 19,636,800,000 BTU. per day, and with coal at 10 cents per million BTU., and with 1 ct. per million BTU. for such labor as is affected, the total saving due to heat balancing is $204.00 per day for the equipment and load curve given.

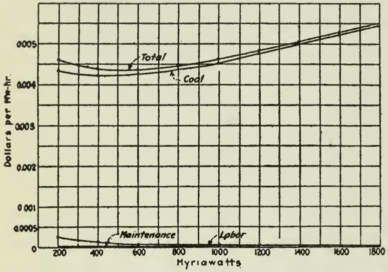


N. PLANT INPUT-OUTPUT LINES, ALL ELECTRIC AUXILIARIES

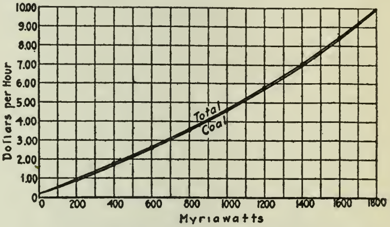
In order to choose between steam and electric-driven auxiliaries, Fig. N, in which the engine-room steam consumption is that of the main units only, while the capacity of the main units is reduced by the amount of current used by the auxiliaries, has been drawn up for comparison with K. It shows that the electric-drive arrangement is thermally less economical, and since the prices of electric-driven auxiliaries, including the portion of the main generator capacity and engine-room equipment used for auxiliary power, are higher than for steam-driven auxiliaries, the cost of the electric auxiliary station per effective installed Kw. is $69.10 as against only $65.00 for the steam auxiliary station. The electric auxiliaries are defeated both on the grounds of operating economy and of investment charge. In the particular plant under discussion consideration was given to separate turbine-driven generating sets supplying current to motor-driven auxiliaries and exhausting steam into feed-water heaters, together with an economizer, but it was found to be less economical, although requiring only 18,000 BTU. per Kw.-hr. as against 19,250 with steam-electric auxiliaries without economizer, and 18,540 for an economizer used in connection with steam-driven auxiliaries, these figures being for one load only. The investment cost per kilowatt is increased by the steam-electric combination from $65.00 to $70.31. The best combination can be determined only from a consideration of the load factor, labor and maintenance cost, and reliability.

Another method of balancing, similar to that described by *Piggott*, is obtained by making some of the auxiliaries both motor and turbine-driven, which permits of regulating the auxiliary exhaust to the amount required to heat the feed water. If, for any reason, motor drive is preferred, the highest economy would be secured by installing an auxiliary generating set exhausting to the feed-water heater, the generator being connected to the main busbars so that it can take power from the main units when it would otherwise produce more exhaust than is required for feed heating, and supply current to the main busbars should the back pressure and the temperature in the heater tend to fall. This operation can easily be made automatic, depending upon the back pressure in the heater, so that no attention on the part of the personnel is required for heat balancing.

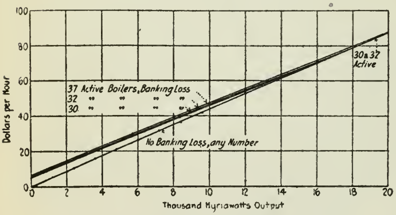
With a fixed number of boilers installed the number which is most economical for carrying various loads can be determined from curves for each boiler-stoker unit, giving the cost per Mw. hr. for maintenance, labor and



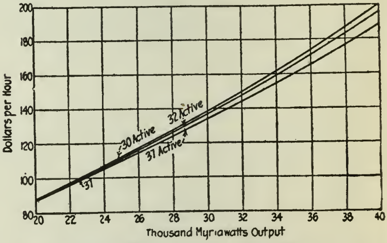
O. COST OF OPERATION PER Mw.-HOUR, 520 Mw. NEW BOILER



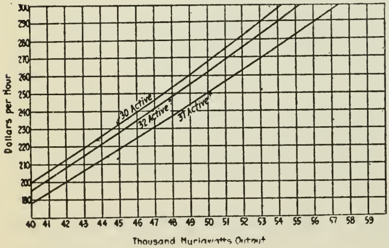
P. OPERATING COST PER HOUR, 520 Mw. NEW BOILER



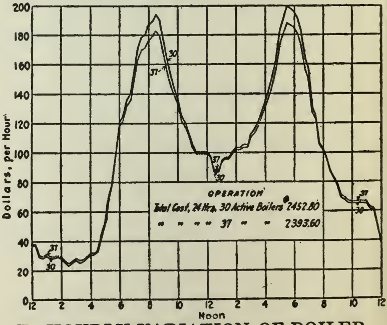
Q VARIATION OF OPERATING COST, LIGHT LOAD



R. OPERATING COST, MEDIUM LOAD



S. VARIATION OF OPERATING COST, HEAVY LOAD



T. HOURLY VARIATION OF BOILER ROOM OPERATING COST, ANTICIPATED WINTER LOAD coal, and the total cost per hr. per boiler at different loads, as in Figs. O and P. The total boiler-room cost in dollars per operated hour is shown for the entire range of load, with different numbers of boilers in operation, in Figs. Q, R and S. By selecting the most efficient combinations to fit different parts of the load curve, the maximum efficiency is obtained, as shown in Fig. T, where 30 boilers are more economical at light loads, and 37 at heavy loads. In a new plant, the greater number of boilers undoubtedly would not pay, as the fixed charges would more than offset the saving in cost of operation.

New Plants.—Where a new plant or the installation of additional equipment is under consideration, interest, depreciation, obsolescence, insurance, taxes, overload capacity and efficiency must be studied in connection with the actual or expected load curve. A load of low load factor (the average daily load expressed as a percentage of the maximum or peak load) is most economically carried by equipment which can be forced to high ratings, although the efficiency at these ratings may not be high. A high load factor, on the other hand, may warrant the installation of a relatively large amount of heating surface, and possibly the building of high stacks, rather than the use of mechanical draft fans, which require an appreciable amount of steam for their operation. The selection of the amount of heating surface is aided by the construction of a diagram in which the abscissæ are total boiler surface and the ordinates are annual costs. For example, the ordinate of the curve for a feed pump (in this case a horizontal straight line, since it is not affected by the rate at which boiler surface is driven) would include interest, depreciation, attendance, heat consumed, etc. The curve for cost of boilers will be an upwardly sloping line. Fuel costs will be represented by a curve having a low spot at a point near the most efficient rate of driving for the average load. Cost of settings, buildings, etc., may show abrupt breaks at points where the number of boilers is changed, etc.

By adding together the ordinates of the separate factors, a total cost curve is obtained, the lowest point in which represents the amount of heating surface which will give the lowest annual cost of steam, in a plant having the assumed load curve, with apparatus of the costs and efficiencies assumed.

No factor should be overlooked. Consideration must be given to any possibility of abandonment of the plant after a limited term of years, or the probability of expansion, the availability of improved apparatus or methods, the division of load between boilers, etc. The plant must be able to take care of the maximum peak with a margin to insure continuity of service.

There are several alternative methods of carrying variable loads. In some plants certain boilers are operated continuously at 150 to 200% overload and banked boilers are cut in to take care of increased loads. Until recently this method has been generally followed in central station practice. In other plants a certain number of boilers are always in service. There are no banked fires, but peak loads are carried by forcing. A third method coming into vogue considers the plant divided into two parts, one taking care of a constant part of the load, this part being operated at maximum efficiency, the other part taking the variable load under either of the first two methods. It is, however, becoming more and more a settled principle, where the stoker equipment permits, to operate all boilers with the load evenly distributed. Boiler-room economics demands that reserve capacity be placed in the coal-burning equipment. Spare boilers are an unquestionable necessity, although proper treatment of the boiler feed water supply reduces the number required. It may be found best to operate the spares at all times, cutting boilers out only for cleaning or repairs, thus reducing the load on each boiler and increasing the efficiency.

BOILER PLANT MANAGEMENT

The most perfect equipment and the most complete knowledge will not result in the highest economy unless they are consistently used in daily operation. As pointed out by *W. N. Polakov*, power plant management is often a haphazard undertaking, and 10 to 30% may be added to the operating cost if the securing of knowledge is left to the resourcefulness of individual employes, usually unaided with even the most elementary instruments for observation, seldom possessing the necessary time and authority for experimentation, and frequently unqualified for scientific research work. We possess usable knowledge only when we can predict the phenomena in time, space and effect from a study of causes and conditions. Designing engineers are able to predetermine accurately the results to be expected from their apparatus, but managers of plants are not always equipped with the knowledge which would enable them to secure the results for which the plant was built. The object of preceding pages is to render available such knowledge insofar as it already exists, and to point out methods for its attainment, as relating to the individual plant. *Polakov* suggests that three distinct steps should be taken, viz.:

(*a*) Investigation as to what conditions result in the highest operating efficiency of each different unit of equipment.

(*b*) Experimentation leading to the discovery of how these best conditions may be secured and maintained at will, and

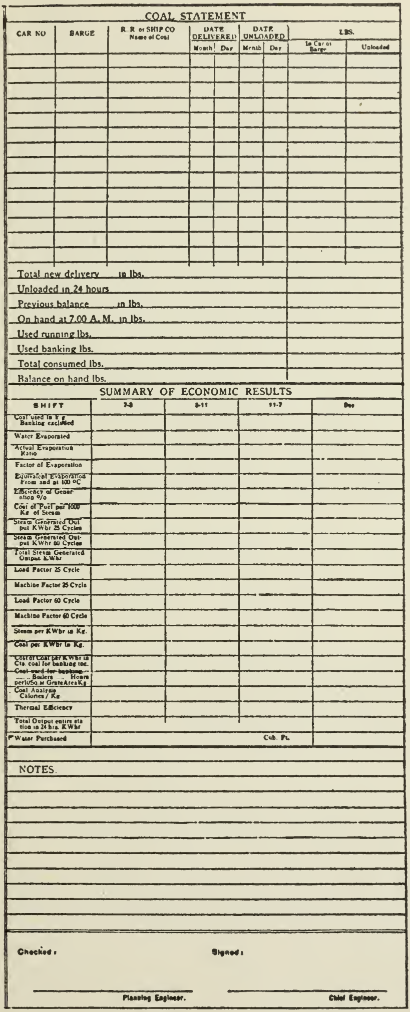
(*c*) Co-ordination of the practice found to be best, in a manner that will show which is the most advantageous inter-relation of these conditions, and the resulting individual efficiency from the following aspects:

(1) Security of operation,
(2) Welfare of employes,
(3) Cost of operation,
(4) Cost of maintenance,
(5) Idle overhead expense.

Planning.—He suggests that the function of securing the knowledge be vested with the plant's planning department, which should assume the permanent duty of carrying out investigations and researches. With every change of condition, such as a new grade of fuel, a different make of supplies, etc., the planning department will start an investigation to find out exactly how to cope with the circumstances.

The time and expense of testing by untrained persons is, as he remarks, a pure waste; oftentimes harm is done for the future by wrong conclusions derived. Tests that are made without keeping complete records of all conditions should not be run at all; only complete and continuous records are useful and dependable. Further, tests that do not take into consideration the human factor will fail of their object, since it may not be feasible for the men to duplicate the test conditions continuously. Test data should be carefully and exhaustively worked out, analyzed immediately, and checked several times by repeated tests to ascertain that results obtained once can be duplicated at will. The object of tests or time-and-motion study being the discovery of the best methods, the work is completed satisfactorily only when the findings are reduced to such plain written instructions that the average employe can live up to them after reasonable training and demonstration.

Polakov points out that the willingness and ability of the employe to do the right thing cannot be utilized unless it is definitely known *what the right thing is* in a given plant under given circumstances, but since the man himself,



COAL STATEMENT

CAR NO	BARGE	R. R. or SHIP CO Name of Coal	DATE DELIVERED		DATE UNLOADED		LBS.	
			Month	Day	Month	Day	In Car or Barge	Unloaded

Total new delivery in lbs.	
Unloaded in 24 hours	
Previous balance in lbs.	
On hand at 7.00 A. M. in lbs.	
Used running lbs.	
Used banking lbs.	
Total consumed lbs.	
Balance on hand lbs.	

SUMMARY OF ECONOMIC RESULTS

SHIFT	7-3	3-11	11-7	Day
Coal used in Kg Banking excluded				
Water Evaporated				
Actual Evaporation Ratio				
Factor of Evaporation				
Equivalent Evaporation From and at 100 °C				
Efficiency of Generation %				
Cost of Fuel per 1000 Kg of Steam				
Steam Generated Output KWhr 25 Cycles				
Steam Generated Output KWhr 60 Cycles				
Total Steam Generated Output KWhr				
Load Factor 25 Cycle				
Machine Factor 25 Cycle				
Load Factor 60 Cycle				
Machine Factor 60 Cycle				
Steam per KWhr in Kg.				
Coal per KWhr in Kg.				
Cost of Coal per KWhr in Cts. coal for banking inc.				
Coal used for banking .... Boilers .... Hours per 10 Sq. M Grate Area Kg				
Coal Analysis Calories / Kg				
Thermal Efficiency				
Total Output entire station in 24 hrs. KWhr				
Water Purchased			Cub. Ft.	

NOTES.

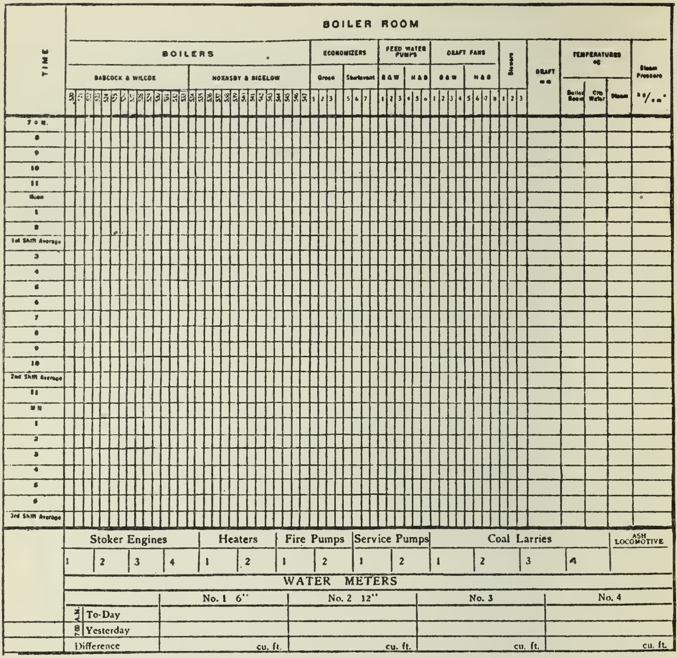
Checked:

Planning Engineer.

Signed:

Chief Engineer.

BOILER ROOM RECORD FORM



BOILER ROOM

TIME

BOILERS: BABCOCK & WILCOX 520 521 522 523 524 525 526 527 528 529 530 531 532 533; HORNSBY & BIGELOW 534 535 536 537 538 539 540 541 542 543 544 545 546 547

ECONOMIZERS: Green 1 2 3; Sturtevant 5 6 7

FEED WATER PUMPS: B&W 1 2 3; H&B 4 5 6

DRAFT FANS: B&W 1 2 3 4; H&B 5 6 7 8

Blowers 1 2 3

DRAFT mm

TEMPERATURES °C: Boiler Room, City Water, Steam

Steam Pressure kg/cm²

7 a.m.
8
9
10
11
Noon
1
2
1st Shift Average
3
4
5
6
7
8
9
10
2nd Shift Average
11
MN
1
2
3
4
5
6
3rd Shift Average

Stoker Engines				Heaters		Fire Pumps		Service Pumps		Coal Larries				ASH LOCOMOTIVE
1	2	3	4	1	2	1	2	1	2	1	2	3	4	

WATER METERS

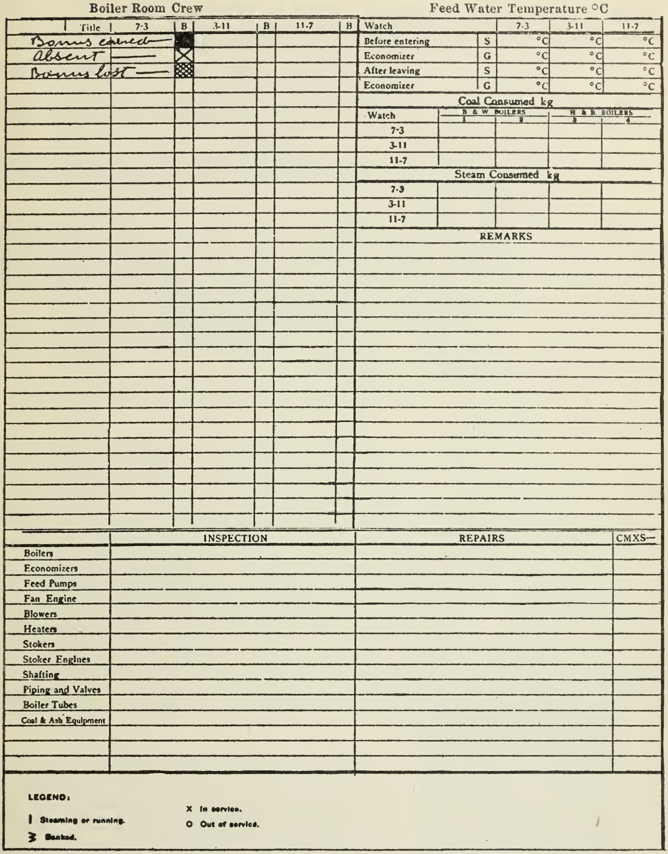
	No. 1 6"	No. 2 12"	No. 3	No. 4
7 A.M. To-Day				
7 A.M. Yesterday				
Difference	cu. ft.	cu. ft.	cu. ft.	cu. ft.

BOILER ROOM RECORD FORM

being employed to do things, seldom possesses the time and facilities to carry out all the necessary research work, it is a mistake to ask men to secure better results without teaching them how to do it, and without providing them with instruments showing the results obtained.

He advocates that the management should assume the responsibility of determining the best conditions of operation, and should then assign to each member of the organization a well-defined task. The study of the task presupposes complete and detailed knowledge of every process performed in the plant, reliable information as to what each unit of equipment can do, and the conditions which produce the desired results. This knowledge, once gained through test and research work, is made available by instructions and training. The duty of the men is to maintain conditions as prescribed. If all requirements are complied with, results will inevitably follow:

Rewards.—Each man should therefore be paid for doing his assigned part of the work in the proper manner and not paid according to the final results, which are beyond the control of any one individual. For example, if the boiler efficiency is lowered because of dirty heating surface, the loss should be charged against the man who has failed to clean it, and not against the fireman, who may have fired properly. The same remarks apply to neglect to prevent leaks in boiler settings and baffles, or to any other item of performance entrusted to specific persons. The maintenance of high



Boiler Room Crew

Title	7-3	B	3-11	B	11-7	B
Bonus earned —		■				
Absent	—	☒				
Bonus lost —		▩				

Feed Water Temperature °C

Watch		7-3	3-11	11-7
Before entering	S	°C	°C	°C
Economizer	G	°C	°C	°C
After leaving	S	°C	°C	°C
Economizer	G	°C	°C	°C

Coal Consumed kg

Watch	B & W BOILERS		H & B. BOILERS	
	1	2	3	4
7-3				
3-11				
11-7				

Steam Consumed kg

7-3				
3-11				
11-7				

REMARKS

	INSPECTION	REPAIRS	CMXS—
Boilers			
Economizers			
Feed Pumps			
Fan Engine			
Blowers			
Heaters			
Stokers			
Stoker Engines			
Shafting			
Piping and Valves			
Boiler Tubes			
Coal & Ash Equipment			

LEGEND:

| Steaming or running.

3 Banked.

X In service.

O Out of service.

BOILER ROOM RECORD FORM

efficiency therefore requires regular and exacting inspection of equipment as well as supervision of labor. Inspection, cleaning and similar work must be performed at reasonable intervals, determined by the planning department.

Each man is rewarded for the performance of his task. Failure to earn the reward or bonus is at once investigated; and if due to the fault of the individual, he receives his day-pay, but loses his bonus; if due to the fault of someone else, the individual is allowed his bonus, and the guilty person loses his. For example, if a new grade of coal should be substituted without proper instructions based on adequate research as to the best manner of burning it, the failure to obtain expected results would be chargeable to the planning department, not to the fire-room boss or to the fireman.

When the bonus is not earned, it may be due to:

(*a*) Fault of man not observing instructions,
(*b*) Fault of maintenance, making observance of instructions impossible or spoiling results,
(*c*) Fault of supplies, the quality of which is not up to standard requirements,
(*d*) Fault of planning department issuing wrong instructions, or at the wrong time, or failing to provide necessary information, training, etc.

Polakov observes that the machinery of planning cannot be operated smoothly unless adequate means are provided for observing and checking the results following the planning done in the past, and if the power plant, and particularly the boiler house, is not provided with all necessary instruments, there is no hope of operating it economically.

Organization.—An organization for carrying out this method of management may be outlined briefly as follows:

The organization is occupied with two different kinds of work, viz., planning and execution.

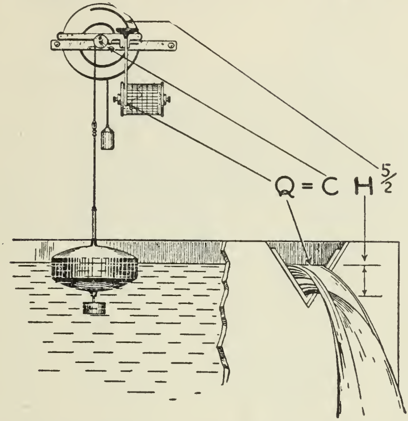
The chief executive of the power plant is the chief engineer. All employes are responsible to him for the proper discharge of their duties, which include proper discipline and compliance with planning office orders.

The planning section is under the supervision of the superintendent, and the planning engineer in charge of the office is responsible to him. The functions of the planning office include order of work, instruction cards, records, time and cost keeping and personnel, including discipline. The planning office receives all requests, and co-operates with the chief engineer, the chief electrician, and the chief maintenance man. The planning office reports to the superintendent of power on the progress of work and success of methods, and transmits to the office of the superintendent of power all records kept in the plant. The organization and co-operation of other departments, such as those ordering and receiving the supplies and material, is obtained by the planning office.

In the boiler room there is a gang boss, who takes charge of conditions for performing the work in each department. He sees that the necessary quantity of coal is delivered to the stokers in time, that water is fed to the boilers in the proper manner by the proper pumps, that each man has definite boilers assigned to him, and that all necessary firing tools, instruction cards, instruments, etc., are given to the men. A work boss is responsible for the performance of the work by each man. His duty is to instruct the men how to work in accordance with the instructions prescribed on the instruction cards. He sees that the coal is fed into the furnace at the proper rate, that stoker and fan engines are running at the right speeds, that the depth of fuel is that required by the instruction cards, and that the draft is always according to the instructions for a given rate of driving. He instructs the fireman when to shake grates, and when and how to clean fires. He must not only advise his men how best to do their work, but must actually demonstrate the best way of doing it and constantly train the firemen.

Record forms used by the boiler room in this system of management are reproduced on pages 259, 260 and 261.

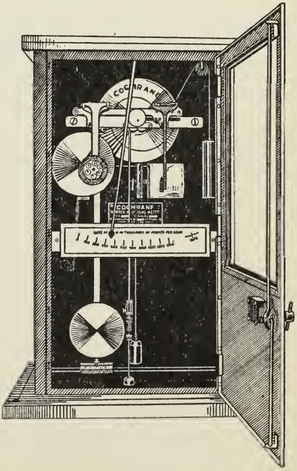
Cochrane Meters



CORRELATION OF FLOAT RISE, CAM ROTATION AND PEN DISPLACEMENT IN COCHRANE V-NOTCH METER AND RECORDER WITH THE FORMULA:

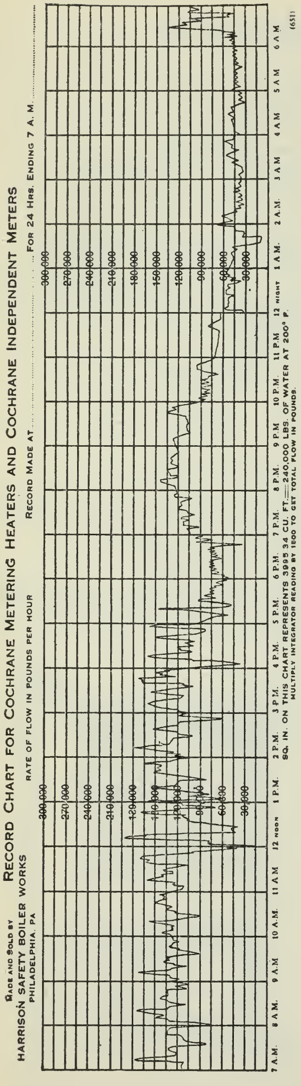
$$\text{Rate of flow} = \text{constant} \times \left(\text{head on the weir}\right)^{5/2}$$

The characteristics and testing of V-notch weirs are discussed exhaustively in *Engineering Bulletin No. 18* of the *Harrison Safety Boiler Works.*

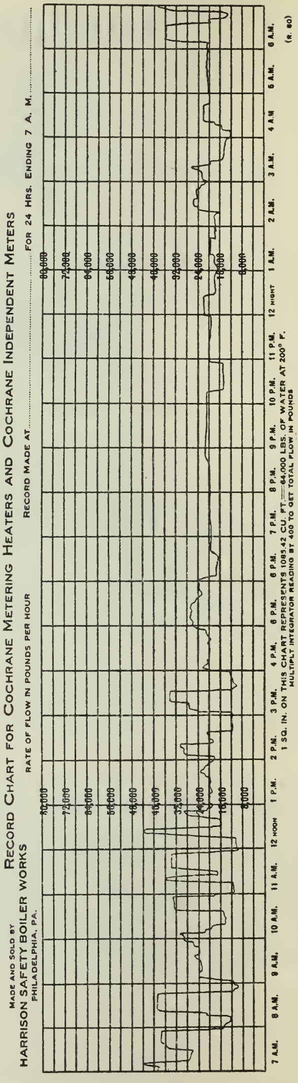


COCHRANE MASTER CLOCK RECORDER

Showing rugged simplicity and ready accessibility of weight-driven pendulum escapement clock, which moves chart record and integrator disk in absolute synchronism. Note dust-proof door lining and triple clamp, which assures protection of instrument against dust and moisture.

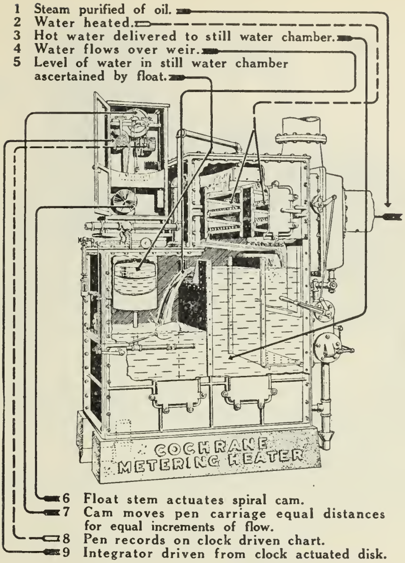


FROM CENTRAL STATION, SHOWING VARIATIONS IN LOAD



FROM STATE INSTITUTION

COCHRANE METER CHARTS, can be integrated by an ordinary steam engine indicator planimeter or totals can be read from automatic integrator of the Recorder.



1 Steam purified of oil.
2 Water heated.
3 Hot water delivered to still water chamber.
4 Water flows over weir.
5 Level of water in still water chamber ascertained by float.
6 Float stem actuates spiral cam.
7 Cam moves pen carriage equal distances for equal increments of flow.
8 Pen records on clock driven chart.
9 Integrator driven from clock actuated disk.

The Cochrane Metering Heater combines the functions of the celebrated Cochrane Heater (of which more than 10,000,000 horse-power are in present successful and satisfactory service) with those of an accurate and reliable feed water meter.

The Heater Part.—The exhaust steam by which the water is heated is first purified of oil by a Cochrane Oil Separator attached to and forming a part of the heater. The steam then flows in, around and between the trays, over which the cold water is being sprayed. This exhaust condensed in heating the water is conserved and utilized to form part of the boiler feed supply.

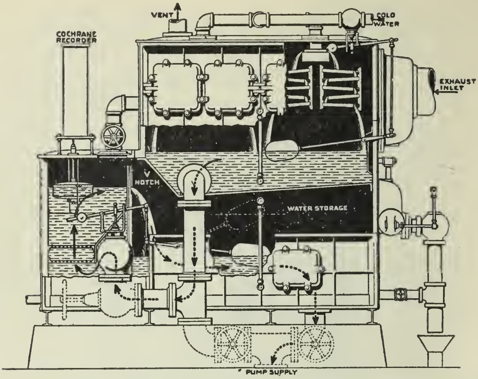
The heater also serves as a hot well or returns tank for the reception of condensate and trap discharges and as an automatic make-up water regulator to supplement such returns by the required amount of cold water.

The Meter Part.—The combined water supplies, just before they pass from the heater to the boiler feed pumps, flow over a V-notch weir.

A powerful float, controlled by the head of water flowing over the weir, actuates a cam by which a pen carriage is moved equal distances for equal increments in the rate of flow.

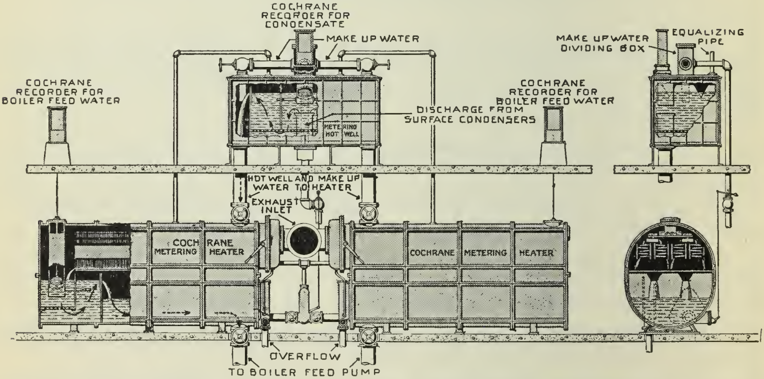
The pen records the rate of flow at each instant upon a clock-driven chart. The area under the pen trace is proportional to the total amount of water passed. An automatic integrator gives immediate indication of totals.

Hundreds of Cochrane Metering Heaters are in successful operation, giving accurate and reliable measurements in the largest and best equipped plants of the United States.



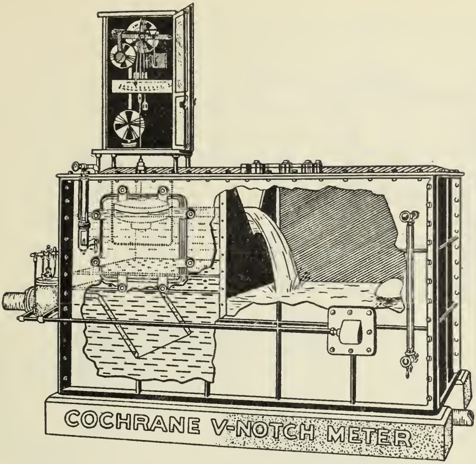
COCHRANE O-SERIES METERING HEATERS AND RECEIVERS WITH ISOLATED METER CHAMBERS, BACK-PRESSURE SERVICE

Used where condensed returns may at times be delivered to the heater in excess of the boiler feed requirements and where outside storage is not provided.


COCHRANE RECORDER FOR CONDENSATE
MAKE UP WATER
MAKE UP WATER DIVIDING BOX
EQUALIZING PIPE
COCHRANE RECORDER FOR BOILER FEED WATER
COCHRANE RECORDER FOR BOILER FEED WATER
DISCHARGE FROM SURFACE CONDENSERS
METERING HOT WELL
HOT WELL AND MAKE UP WATER TO HEATER
EXHAUST INLET
COCHRANE METERING HEATER
COCHRANE METERING HEATER
OVERFLOW
TO BOILER FEED PUMP

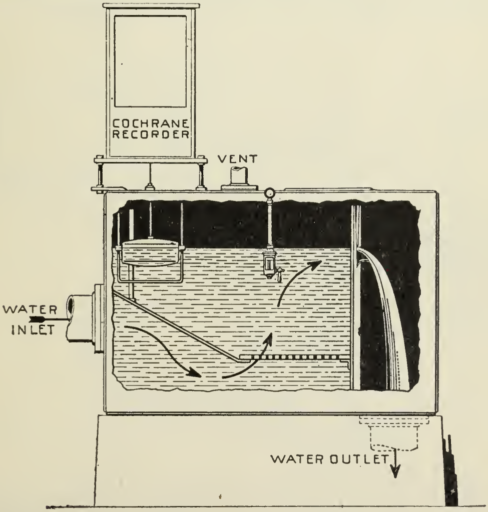
COCHRANE PATENTED DOUBLE UNIT METERING ARRANGEMENT WITH METERING HOT WELL

The Cochrane Metering Hot Well on the upper floor measures the condenser returns, automatically admits the required amount of make-up water and divides the whole into equal parts, which pass to the two Cochrane Horizontal Elliptical Metering Heaters below, which register the total boiler feed. All three recorders are located on the turbine room floor. Capacity, 1,200,000 lb. per hour.

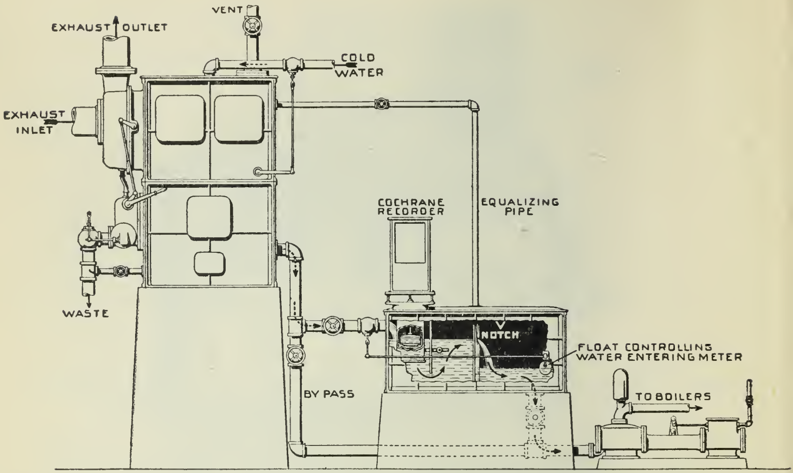


COCHRANE O-SERIES INDEPENDENT METER

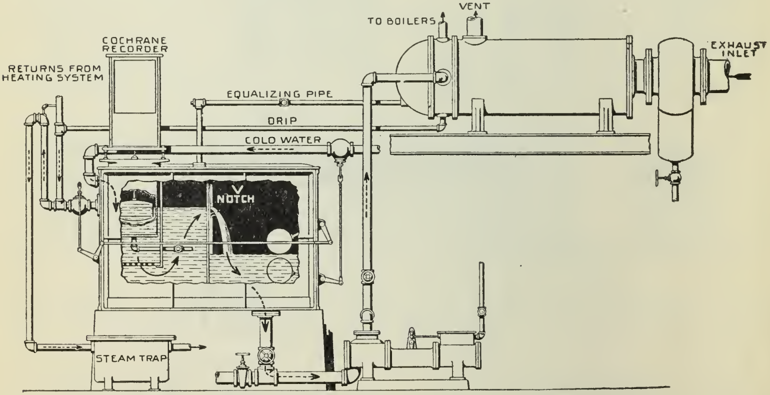
With Recorder float resting directly on water in approach chamber. Inlet valve controlled by float in out-flow chamber.



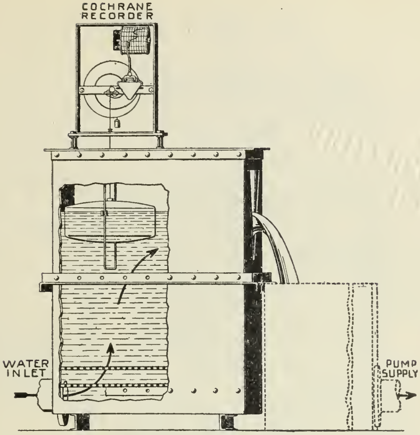
COCHRANE INDEPENDENT STEEL PLATE METER FOR MEASURING CONDENSATE AND OTHER LIQUIDS WHERE CONTROL VALVE IS NOT REQUIRED



PATENTED METHOD OF INSTALLING COCHRANE INDEPENDENT METER IN CONNECTION WITH OPEN FEED WATER HEATER BY WHICH ANNOYANCE FROM ESCAPE OF VAPOR AND LOSS OF HEAT WHEN WATER IS ABOVE 212 DEGREES F., AS WITH BACK PRESSURE, IS PREVENTED

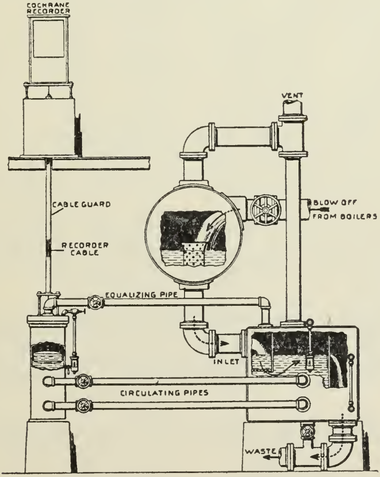


COCHRANE FEED WATER METER ARRANGED FOR USE WITH CLOSED HEATER IN CONNECTION WITH EXHAUST STEAM HEATING SYSTEM. METER SERVES ALSO AS HOT WELL FOR RETURNS AND ACTS AS AUTOMATIC MAKE-UP WATER REGULATOR



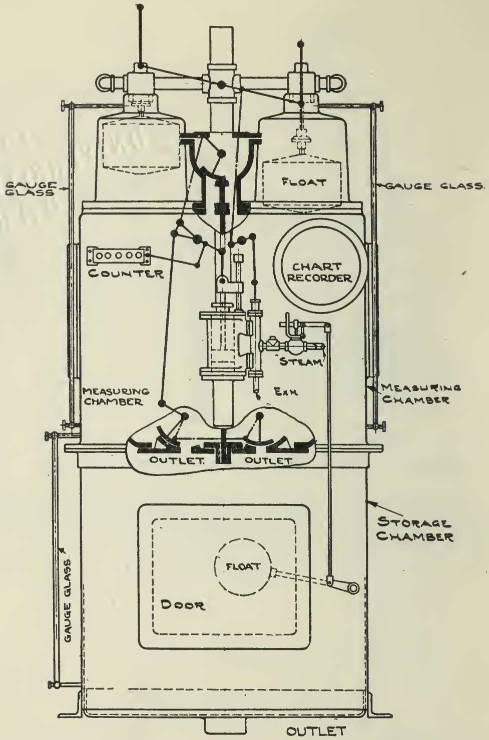
COCHRANE PORTABLE METER, WITH DEMOUNTABLE RECORDER

Height of tank 45 in., width and length 30 in. Supplied with V-notches having a maximum capacity of 5,000 to 125,000 lbs. per hr. The Recorder packs within the meter chamber for shipment.



COCHRANE BOILER BLOW-OFF METERING ARRANGEMENT

The Recorder is so arranged that leakage of blow-off valves is recorded on a magnified scale.



PRINCIPLE OF COCHRANE PRECISION METER

The two chambers are alternately filled and emptied by the action of the valves, which cannot throw until one chamber is completely emptied and the other completely filled. Extensively used for measuring fuel oil and condensate on board ship.

Cochrane appliances for measuring and recording boiler feed, condensate, blow-off, heating returns, cooling water, etc., are covered in our Catalogue No. 820, sent upon request. This publication contains photographs of actual installations with full descriptive matter on the various types of apparatus.

HARRISON SAFETY BOILER WORKS

INDEX

Page
Abbott....208
Absorption, heat....187–226, 227
  Improving....206
Acid correction with calorimeter.... 33
Acids in water....221
Agnew, A. L....183
Air:
  Properties of....6, 249
  For combustion....65, 67
  Excess required....68, 70, 161, 171, 181
  Excess furnished..76, 82, 100, 121, 122, 161
  Reducing excess....161, 166
  Corrosion by air....221
  Moisture in....237
  Air heaters....198, 200
Alden, J. L....135
American Chemical Society.... 23
American Engineering Co. Stoker.97, 131, 178
American Society of Mechanical Engineers...14, 24, 27, 29, 30, 31,
145, 209, 227, 239, 246
Anthracite, characteristics....5, 6, 45, 46
  Sizes....14, 41
  Specifications.... 55
  How to burn.... 78
Arches, ignition and mixing....171, 212
Asbestos covering....216
Ash, nature and determination....27, 30, 36
  Government allowance....46, 54, 55
  Effect on heating value.... 42
  Effect on efficiency....243
  Fusing temperature.... 38
  Loss due to combustible in ash....234, 236
  Ash pits....213
Aspirator....146
Auxiliaries, steam plant....224, 226, 252, 254
Azbe, J.... 68
B. T. U.... 31
B. & W. Chain Grate....86, 115, 130
Babcock & Wilcox Co....197, 199
Bacharach, Herman....153
Baffling....206, 208, 211
Bailey, E. J....170
Bailey Boiler Meter....137
Balancing, heat....254
Bancel, P. A....113
Barkley....140, 143
Barnhurst, H. C....185, 186
Baumé scale.... 60
Bell, J. E....192, 195, 197
Bement, A....42, 157, 158, 208
Bicarbonates....219
Bimeter CO_2 Recorder....151
Bituminous coal, characteristics.... 5, 6
  Sizes.... 14
  How to burn.... 78
Bleeding steam....226, 254
Blonck Efficiency Meter....137
Blow-off meter....269
Boilers:
  Heating surface....198, 202, 206, 207, 209
  Settings....166, 172, 211
  Efficiency....227, 238, 252
  Efficiency and economy.... 41
  Efficiency and capacity...41, 207, 210, 245
  Efficiency and gas temperature....140, 157
  Efficiency and CO_2....157

Boilers—Continued: Page
  Efficiency and CO....160
  Efficiency and excess air....239
  With different coals....240
  Tests....246, 249
Boltzmann....192
Bomb calorimeter....31, 61
Bonus, fireman's....261
Breechings....116, 119, 123
British thermal unit.... 31
Broido, B. N....179
Bureau of Mines, 7, 8, 21, 22, 23, 24, 25, 26
27, 29, 30, 31, 32, 33, 44, 45, 46, 47, 49, 57
58, 59, 68, 73, 74, 75, 78, 79, 81, 83, 100
101, 102, 106, 109, 111, 133, 138, 139, 140
143, 144, 145, 146, 147, 151, 154, 158, 161
163, 171, 187, 190, 202, 206, 211, 212, 213
216, 239, 240, 241.
Bureau of Standards....31, 33, 102, 214
Burners, oil....180
  Powdered coal....185
CO = carbon monoxide
CO_2 = carbon dioxide
Calcium salts....219
Calorie.... 31
Calorimeter....31, 61
Cambridge Scientific Instrument Co....151
Campbell, M. R.... 5
Carbon, fixed, determination.... 27
  Heating value.... 66
  Effect on heating value....5, 35
  Effect on efficiency....241
Carbon, total, determination.... 29
Carbon-hydrogen ratio.... 5
Carbon dioxide:
  Formation.... 66
  Determination....144, 150, 151
  And furnace temperature....101
  And efficiency....157, 165
  And gas quantities....121, 122, 163
  General comments...106, 121, 156, 159, 162
  In water....219, 221
Carbon monoxide, formation.... 66
  Determination....148, 149, 151
  From reduction of CO_2....66, 107
  Effects of....76, 156, 158, 168
  Heat loss from....227
Carbonates in water....219
Carey, A. A.... 73
Carpenter, R. C....238
Carrier....197
Centennial Exposition....210
Chain grates....84, 87, 115, 129, 177
Chimney sizes and draft....119–129
Chimney gases, heat loss in....232
Chlorides....220
Clinker....37, 109
Coal:
  Classification of....5, 10, 39
  Purchase of.... 45
  Sampling.... 15
  Analysis, proximate.... 23
  Analysis, ultimate.... 28
  Typical analyses.... 10
  Heating values....5, 7, 10, 31, 35
  Efficiencies obtainable with....240
  Steaming value.... 41
  Measurement and handling....57, 59, 185

Page
Cochrane Heaters....224
Cochrane Meters....227, 263
Combustible in coal....27, 66
Combustible in ash, loss due to....234, 236
Combustion....66–186
Combustion, spontaneous.... 58
Combustion space....108, 211
Combustion Engineering Co..87, 95, 130, 131
Commonwealth Edison Co....208
Conduction, heat transmission by....187
Conduits, friction loss in....115
Conklin, A. W....217
Convection, heat transmission by....192
Conversion factors....249
Cook, G. C.... 42
Corrosion....221
Cosgrove, J. F....5, 6, 39
Coxe Traveling Grate....87, 130
Coxe-Fulton Stoker.... 91
Coverings, boiler and pipe....216
Culliney, J. V....185
D'Amour....103
Dampers....77, 137
Deinlein....105
Detroit Side-Feed Stoker.... 92
Draft requirements....81, 110, 138, 156
  Required by boilers....112
  Required by fuel bed....113
  Flue proportions....115
  Stack proportions....119–129
  Required by stokers....129
Draft, mechanical....132
Draft gages....135
Du Long....29, 36, 44
Economizers:
  Economy of....198, 255
  Heat transmission....198, 200, 203, 205
  Draft requirements....116
Edge, W. C.... 76
Edgemoor boiler....113
Electric auxiliaries....255
Ellison draft gage....136
Engler scale.... 60
Eschka.... 30
Evans, W. A....183, 186
Evaporation rate..117, 202, 203, 210, 248, 264
Evaporation, equivalent....210, 228
Exhaust steam utilization....226
Factor of evaporation....210
Factors, conversion....249
Fans, draft....132, 251
Feed water heating....224, 254, 265, 266
  Scale-forming feed water....210
Feild.... 39
Fessenden....199
Fieldner.... 39
Finlay....209
Fire-brick....213
Firing, hand....73, 262
  Clinker prevention....109
  Smoke prevention....171
  Effect on CO_2....157
Firing, stoker....87, 91, 94, 95, 98, 157, 159
Fisher, H. D....237, 238
Fiske, E. W....218
Flash point of oil.... 60
Flow recorder....263
Flue proportions....115, 124
Flue gas analysis....144
Forced draft....132
Forcing boilers....207, 210

Page
Friction loss of draft....115, 123
Fry, Lawford H....199
Fuchs....168
Fuels....5–185
Fuel bed:
  Depth of....78, 81, 100, 114
  Resistance of....111, 113
Furnaces:
  Adaptation to coal.... 42
  Proportioning....108, 206, 211
  Smoke prevention....172
Fusing temperature of ash.... 38
  Fire-brick....214
Gases, properties of....65, 144, 234
  Thermal capacities....103
  Of combustion, amount 104, 106, 108, 120, 162
  Temperatures....139, 197, 199, 202, 208
  Sampling....146
  Analysis of....144, 147
  Loss in chimney gases....232
Gas passages and heat absorption...117, 206
Gaseous fuels....64, 182
Gebhardt....72, 216
Gensch, M....44, 76, 124, 163
Gibson, G. H....200, 202, 203
Glaser furnace.... 29
Goss....202
Gould.... 41
Gram calorie.... 31
Grates.... 72
Gravity stokers.... 97
Green Chain Grate....84, 115, 130, 178
Hall.... 39
Hall, R. T....170
Hand firing.... 73
Hardness of water....219
Harrington, Jos....115, 172, 183, 185
Hays, Jos. W., 31, 58, 74, 75, 78, 100, 137, 139, 144, 145, 156, 158, 166, 167, 212, 235, 237, 239, 249
Hays Differential Draft Gage....135
Heat, absorption of....187–226, 227
  Generated and absorbed..66, 202, 206, 207, 218, 227
  Transfer from fluid in channel....197, 199
  Heat balance....227–238
  Effect on reactions....222
  Balancing....254
Heaters:
  Air....200
  Open feed water....224, 254, 268
  Metering....265, 266, 268
Heating surface, boiler.198, 202, 206, 207, 209
Heating value of coal....5, 7, 10
  Determination of....31, 34, 36
  High and low values....31, 64
Heating value of gases.... 65
Heating value of oils....61, 64
Herberg, G....121, 162
Heraeus electric furnace.... 29
Hoe, fireman's.... 79
Horse-power, boiler....209
Hot process water softening....223
Howden....200
Hubbard, C. W....235
Hudson, C. B....178
Humidity....237
Hydrogen, heating value of.... 66

Page
Hydrogen in coal, determination of 29, 31
  "Available" 7, 69, 163
  Loss due to 231
  Effect on smoke 169
Hydrogen in moisture, correction for 28
Hydrogen and corrosion 221
Ignition arch 212
Illinois Central R. R 218
Illinois Stoker 84, 129
Inchley, W 61
Input-output lines 252
Interboro Rapid Transit Co 207, 251
Isocalorific lines 7
Isovolatile lines 7
Jacobus 202
Jones Stoker 94, 178
Jordan 199, 200
Josse 199
Kent 35, 126
Kilogram calorie 31
Kjeldahl-Gunning 29
Kratz, A. P 82
Kreisinger 140, 143, 192, 198
Kropff 61
Laclede-Christy Stoker 85, 130
Ladle, sampling 21
Leeds & Northrup 101
Leakage, air 145, 163, 166
Lehigh Stoker 131
Lignite, characteristics 5, 6, 25
  How to burn 79
Linde, P. C 139, 237
Load variation 202, 203, 226, 245, 252, 256, 264
Longmans, Green & Co 229
Lucke, C. E 61, 64, 202, 203, 206
Magnesia covering 216
Magnesium salts 219
Maguire, T. F. J 115
Management, boiler plant 258
Marks 39, 40, 72, 180, 182, 194
Marks & Davis 229, 250
Mass action in combustion 70
Massachusetts Institute of Technology 221
Maxwell, Clerk 189
Mechanical draft 132
Meker burner 26
Mellor, J. W 214
Menzin, A. L 113, 115, 116, 119, 123, 125
Meters:
  Coal 59
  Water 41, 227, 246, 247, 263
  Oil 270
  CO_2 151
Methane 64
Missouri, Kansas and Topeka R. R 185, 186
Mixing arch 172, 213
Moisture in coal:
  Determination 19, 24, 30
  Specifications covering 46, 54
  Effect of 43, 58, 183, 241
  Heat loss from 228
Moisture in air, heat loss from 237
Molecular weights of gases 144
Moller 35
Moloch Stoker 97, 132
Monnett, Osborne 119, 128, 137, 172, 173, 212
Moore & Co., C. C 62
Motor-driven auxiliaries 254
Moyer, J. A 45
Murphy Stoker 90, 92, 109, 130

Page
Natural gas 64
Nelson 62, 180
Nelson Blower and Furnace Co. 97, 132
Nitrogen in coal, determination of 29
Nitrogen correction with calorimeter 33, 35
Nitrogen in air 68
Nusselt 199
Oil fuels:
  Nature and value 60
  Burning 180
  Heat absorption from 202–206
  Measuring 270
O'Neill, H 163, 228, 232
Open heaters 224, 254, 265, 268
Optical pyrometer 101, 141
Orrok 113
Orsat apparatus 147
Overfeed stokers 88, 91, 130
Oxygen in coal, determination 28
  Effect of 43
Oxygen in air, action of 66, 161
Oxygen in flue gas 148, 149, 151, 161
Oxygen in water 221
Palmenburg 39
Parr 8, 27
Paulding 216
Peabody, E. H 34
Peat 5, 7
Pennsylvania R. R 199
Pfaundler 33
Piggott, R. J. S 251
Pinther burner 185
Planning department 258
Plant proportioning 251
  Management 258
Playford Stoker 84, 129
Polakov, W. N 258
Potassium salts 220
Powdered coal 182
Power 36, 78
Pratt, A. D 133
Precision Instrument Co 153
Pressure drop through boilers 111, 113
Producer gas 64
Proportioning boiler plants 251
Proximate analysis 10, 23
Psychrometer 237
Pulverized coal 182
Pumps, steam consumption 252
Pyrite 29
Pyrometers 101, 139, 141
Radiation:
  Heat transmission by 192, 202, 207
  Temperature readings 33, 105, 139, 140, 208
  Losses 238
Railway Fuel Association 182
Rake, fire-room 79
Rankine 198
Reagents for water softening 219, 223
Recorders, flow 263
Recorders, CO_2 151
Records, boiler room 259
Refractories 213
Regnault 33
Reutlinger, E 217
Rewards 260
Reynolds, Osborne 192
Richters 58
Riley Stoker 97, 99, 131
Ringelmann 169, 170
Rolston, O. C 7

Page
Roney Stoker 88, 92, 130, 207
Rosedale Foundry and Machine Co. .. 84, 129
St. Louis Testing Plant 168
Sampling coal 15
  Gases of combustion 144, 156
Santa Fe R. R 62
Sarco Combustion Recorder 154
Scale, effects on heat transmission .. 189, 217
  Forming substances 219
Scales for coal 59
Schmidt 218
Schwartzkopff 185
Seger cones 39
Selvey, W. N 238
Service test 52
Settings, boiler 166, 172, 211
Sherman 61
Simmance-Abady Recorder 153
Simplex Traveling Grate 85
Sizes of coal 14, 43
Slice bar 79
Smith, Morgan B 48, 166
Smithsonian Tables 189, 234
Smoke 167
  Determinations 169
  Prevention 42, 119, 128, 171
Sodium salts 220
Softeners, water 222
Solutions for Orsat 149
Soot 189, 216
Sparrow, J. P 38, 40
Specific heat of gases 232
  Of water 250
Specifications for coal 45, 48, 49
Speller, F. H 221
Spontaneous combustion 58
Spreading method of firing 73
Stack proportions 119
Stanton 199
Steam 5, 6, 14, 67, 68, 82, 112, 113, 114, 119, 126, 156, 214, 217, 234, 245
Steam consumption 251
Steam jet 132, 172
Steam table 229
Stefan 192
Stevens Stoker 97, 132
Stokers, mechanical 84
  Draft required by 129
  Single and double 207
  Adaptation to coal 42
  Steam consumption 251
  Smoke prevention 177
Storage of coal 57, 185
Storage of oil 61, 181
Stott 207
Straight-line law 202, 203
Stripe, W. C 35, 117
Sulphates in boiler water 219
Sulphur in coal 39, 44, 46, 59
  Determination of 28, 29
  Correction with calorimeter 33

Page
Superheaters 179, 201, 210, 228
Swift Throwing Stoker 93
Taylor Stoker 97, 98, 131, 178
Telezometer 153
Temperature:
  Combustion temperature. 100, 103, 157, 165
  Relations in heat absorption 188, 218
  Drop of gases 140, 190, 197, 199, 202
  Effect on radiation 192, 195
  Drop in economizers 200
  Measurement of 33, 101, 139, 208
Terman, J. E 149
Testing boilers 227, 246, 249
Thermocouples 101, 139
Thermometers 139, 143, 208
Throwing stoker 93
Traveling grates 84, 129
Tri-linear coordinates 7
Trials, boiler 246
Trinks 207
Turbine, steam consumption 224, 251
U-tube 135
Uehling, E. A 129, 166
Uehling CO_2 Machine 154
Unaccounted-for loss 238
Underfeed stokers 94, 97, 131, 178
Underfeed Stoker Co 201
Units of measure 250
University of Illinois 57, 82, 196, 218
U. S. Geological Survey 6, 235
U. S. Government specifications 15, 49
U. S. Naval Liquid Fuel Board 181
V-notch weirs 263
Vapor in atmosphere 238
Viall, S, H 172
Viscosity of oils 60, 181
Volatile in coal:
  Classification by 5, 44, 47
  Effect of 58, 76, 171, 240
  Determination 25
Vulcan Soot Blower 216
Walker, W. H 221
Wall, heat transfer to 197, 199
Wall construction 212
Wanner Optical Pyrometer 102, 141
Washing coal 57
Water:
  Properties of 221, 249, 250
  Boiler feed 218
  Softening 221
  Heating 224
  Vapor 238
Water equivalent of calorimeter 33
Weathering of coal 57
Weighing coal 59
Westinghouse Stokers 88, 97, 130, 131
Wetzel Stoker 89, 130
White & Taylor 101
Willans lines 251
Wisconsin State Capitol 21

UNIVERSITY OF ILLINOIS-URBANA
3 0112 112053126